Natural Resource Injury Report on Riparian and Upland Areas of Grant-Kohrs Ranch National Historic Site

Clark Fork River Basin, Montana

Final Report

prepared for

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by

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PREFACE

This *Natural Resource Injury Report* characterizes the magnitude of injury from mining activities to natural resources held by the U. S. Department of the Interior (DOI) along the Upper Clark Fork River, Montana. Data from recent studies conducted on the Grant-Kohrs Ranch National Historic Site (GRKO) were integrated with historical information of the area. Key foundation documents included the *Terrestrial Resources Injury Assessment Report, Upper Clark Fork River Basin* prepared for State of Montana Natural Resource Damage Litigation Program, the U. S. Environmental Protection Agency Ecological Risk Assessment, and several historical studies of the DOI lands.

The historical studies of the DOI lands make important contributions to the overall understanding of the impact of contaminants on the natural resources. These studies (summarized in Appendix A) examined specific impacts of metals on plant communities, phytotoxicity, soil invertebrates, and livestock. Some results demonstrated clear adverse effects on the resources, others did not. None of the early studies was designed to provide all the necessary linkages required to characterize injury as dictated under current regulations. Therefore, more recent studies were designed with the purpose of meeting regulatory guidelines under 43 C.F.R. Part 11.

Information from the following data reports constitutes the primary basis for the determination and quantification of injury as presented in this Natural Resource Injury Report:

- Gannon, J. E. and M. Rillig. 2002. *Relationship of Heavy Metals to Soil Respiration, Grant-Kohrs Ranch and Bureau of Land Management Holdings, Montana*. University of Montana, Missoula.

- Kapustka, L. A. 2002. *Phytotoxicity Tests on Soils from the Grant-Kohrs Ranch National Historic Site, Deer Lodge, Montana.* **e**cological **p**lanning and **t**oxicology, inc., Corvallis, OR.

- Moore, J. N. and W. W. Woessner. 2001. *Geologic, Soil Water, and Groundwater Resources Report, Grant-Kohrs Ranch National Historic Site*. University of Montana, Missoula.

- Woessner, W. W. and M. M. Johnson. 2002. *Water Resource Characterization Report, 2000-2001*. Field Seasons at Grant-Kohrs Ranch National Historical Site. Technical Data Report submitted to the USDOI, NPS.

- Moore, J. N., B. Swanson, and C. Wheeler. 2001. *Geochemistry and Fluvial Geomorphology of Grant–Kohrs Ranch National Historic Site.* Department of Geology, University of Montana, Missoula, MT 59804-1296.

- Rice P. M. and J. Hardin. 2002. *Riparian Plant Community Structure at Grant-Kohrs Ranch*. Final Technical Data Report submitted to U.S. Department of Interior.

- Rice, P. M. 2002a. *Baseline Vegetation Types and Restoration Goals for Grant-Kohrs Ranch*. Final Technical Data Report submitted to U.S. Department of Interior.

- Rice, P. M. 2002b. *Toxic Metals – pH Impact on Riparian Plant Community Structure at Grant-Kohrs Ranch*. Final Technical Data Report to U.S. Department of Interior.

Data were reviewed to assess quality and assign Quality Assurance levels by Dennis R. Neuman, director of the Resource Reclamation Unit, Montana State University, Bozeman. Almost all data were deemed "Enforcement Quality" as defined in the checklist procedures agreed to by ARCO and USEPA in 2000 for data generated at the Clark Fork River Superfund Sites.

The Record of Decision (ROD) for the Clark Fork River is scheduled to be issued by the US EPA in September 2002. Given the time frame for injury determination and natural resource damage claims development established under the under the Streamside Tailings Operable Unit Consent Decree (SSTOU, 19 April 1999), it was necessary to perform this assessment independent from and without the foreknowledge of, the final remedy for the Clark Fork River Operable Unit. Consequently, the remedy chosen in the ROD may remove from consideration some of the areas identified as injured in this report.

EXECUTIVE SUMMARY

This *Natural Resource Injury Report* documents the magnitude of injury from mining activities to natural resources of the Department of the Interior in the Clark Fork River Basin. The National Park Service administers the Grant-Kohrs Ranch National Historic Site (GRKO) in Deer Lodge, Montana. This Report builds upon previous work conducted by the State of Montana in its Natural Resource Injury Assessment of areas within the Upper Clark Fork River Basin. In particular, this assessment focuses on injury to soils of the riparian areas and historically irrigated fields of the DOI.

The Constituents of Concern (CoC) emanating from past mining activities and from continuing upstream releases are arsenic (As), cadmium (Cd), copper (Cu), lead (Pb), and zinc (Zn). Baseline concentrations were identified for As, Cd, Cu, Pb, and Zn from analyses of the soil profiles on the GRKO. Measures of contamination revealed that:

- All surface soil samples in the GRKO floodplain had As, Cu, Pb, and Zn concentrations greater than 5-times the baseline value. Many samples outside the bounds of the floodplain (i.e., in historically irrigated fields, irrigation ditch sediments, and uplands) also showed elevated CoC concentrations.

- Copper concentrations in GRKO surface soils were up to 525-times the baseline.

- The total volume of GRKO soils with CoC >5-times baseline concentrations ranges from 293,000 m^3 (median depth) to 1,660,000 m^3 (maximum depth).

Of particular note, heterogeneous distribution of tailings occurs across the floodplain. This includes the presence of tailings buried under differing thickness of relatively uncontaminated soil. These hazardous substances in the soil are exchanged and transported in soil pore water and groundwater. Because moisture-deficit conditions are common in the region, especially in mid- to late summer, contaminants are frequently transported toward the soil surface.

Exposure to these hazardous substances results in direct toxicity to plants, loss of critical ecological functions mediated by microbes, loss of primary production, deviation of plant community composition from that expected for the area, and restricted development of root systems of plants. Studies demonstrated that:

- Growth and survival of herbaceous and woody species in controlled laboratory tests decreased as CoC (in particular pH-adjusted As, Cu, and Zn) levels increased.

- Root growth was among the most sensitive endpoints in all species tested.

- Aboveground herbaceous plant growth measured in field clip plots decreased as pH-adjusted As, Cu, and Zn levels increased.

- Patterns of plant cover on a small-scale (50 m^2 area) differed in relation to levels of CoC; known metal tolerant species were more prominent as pH-adjusted As, Cu, and Zn levels increased (e.g., tufted hairgrass, redtop bentgrass, and booth willow).

- Riparian plant community structure on a macro-scale (defined by recognizable breaks in species composition) deviated from expected baseline conditions in 63% of the GRKO riparian area.

- Patterns of soil respiration (a measure primarily of microbial activity) differed in relation to levels of CoC.

- Patterns of microbial community structure differed in relation to levels of CoC.

Adverse impact to critical ecological functions carried out by soil microbes has long-lasting negative consequences. These effects include:

- loss of agricultural/livestock production potential;
- loss of recovery potential should other disturbances such as fire occur;
- disruption or alteration of elemental cycles such as carbon and nitrogen; and
- land degradation such as soil erosion and desertification.

Episodic appearance of dead or dying vegetation results from the dynamic nature of physical transport mechanisms. The CoC are mobilized and reach elevated concentrations in the root zone of established plant communities during drying periods. Suppression of root development also may contribute to the high rate of streambank failure noted along several reaches of the GRKO streamside.

Such occurrences negatively affect productivity of the land and alter plant community structure. Consequently, the aesthetic quality of the area is diminished significantly and precludes full attainment of ecological services as required for proper management of the lands under the Congressional mandate given to the National Park Service through the Organic Act of 1916 and the Grant-Kohrs Ranch National Historic Site Enabling Legislation of 1972. Qualitative observations made during the studies included:

- streambank erosion, which exposed buried tailings;
- dead or decadent stands of willows and grasses associated with both slickens and buried tailings;
- areas with decadent vegetation, which in previous years were photographed showing plants having nominal appearance;
- areas with greenish-blue crystals formed on the soil surface and on dead plant stalks; and
- discolored (greenish-blue) bones on the soil surface.

Currently, there are 3.2 ha (~7.9 ac) of exposed tailings or slickens on the GRKO recognized as barren areas and fringes, which are partially vegetated by tufted hairgrass. Additionally, numerous patches too small to quantify spatially in GIS (i.e., 1 to 2 m^2) were observed across the floodplain. Vegetation within the fenced riparian zone has plant communities that differ significantly from the expected baseline communities, totaling 32.8 hectares (80.4 ac) or 63.4% of the area. Despite the exclusion of cattle from the fenced riparian zone since May 1994, plant communities have been slow to recover. Absent hazardous substances in the soils of the riparian area, more recovery of the plant communities would have occurred during this time.

Spatial heterogeneity (both vertical and horizontal) and the dynamic nature of the buried tailings preclude simple delineation of surficial deposits to define the extent of injury. Soil core, soil pit, and bank profile data indicated that surface soils generally had higher CoC concentrations than deeper soils. However, several samples demonstrated that lenses of highly contaminated soils occur below relatively uncontaminated surface soil; indeed the highest concentrations were observed in soil layers below the surface. Paired surface samples separated horizontally by five meters revealed that distributions of CoC were highly patchy. The degree of patchiness is such that techniques such as krieging, which are used commonly to delineate zones of contamination, cannot be relied upon for this portion of the floodplain. Full characterization of spatial distribution would require sampling to be at less than 5-m distances, and therefore is clearly cost-prohibitive. Alternatively, characterization of the magnitude of contamination was done using a probabilistic approach. Data from soil core samples (e.g., concentrations at various depths) were used to determine the probability of encountering contamination at depth.

Levels of As, Cu, and Zn in surface soils consistently exceeded published phytotoxicity thresholds. A weighting factor, which incorporated the influence of pH, was used to relate concentrations to phytotoxic responses. This unitless factor ranged from 0.9 to 14.6 for the GRKO surface samples. Statistically significant and biologically relevant phytotoxicity occurred at pH-adjusted As, Cu, and Zn levels above 3.0. Based on the relationships developed from tests on surface soil samples, predictions of phytotoxic responses to other samples from the riparian zone were made based on alfalfa, alder, and field-measured productivity levels. For the GRKO active floodplain area, the probability of encountering phytotoxic conditions in surface soils (0 to 15 cm depth) was 71 to 76% for alder, 81% for alfalfa, and 86 to 91% for herbaceous productivity. Multiplying the active floodplain area (i.e., 54.44 ha; 134.53 ac) by the probability of encountering phytotoxic levels indicated that up to 46.79 ha (115.7 ac) of surface soil are injured. This declined at 50 cm depth to 33% of the area for alfalfa and herbaceous productivity and 29% of the area for alder. A total of 18.15 ha (44.84 ac) of soil at these intermediate soil depths are injured (33% of fenced riparian zone). At depths of 100 to 150 cm, the probabilities declined further to 0 to 15%, corresponding to 8.17 ha (20.18 ac) of injured soil. Concentrations of some samples at 125 cm depth suggest >50% inhibition of plant growth.

Similarly, more than 75% of the uppermost layer of soil in the GRKO riparian area is injured as indicated by soil (microbial) respiration. With depth, the likelihood of encountering toxic levels decreases such that at 37.5-cm depth, the likelihood of encountering toxic levels to microbes is 27%. Heterogeneous distribution of CoC indicates that the likelihood of toxic levels to microbes rises from 37.5 to 50 cm and again from approximately 70 to 90 cm. Based on the injury endpoints of phytotoxicity, productivity, and microbial respiration:

- the volume of injured soil in the GRKO riparian area was determined to range from 8,447 to 12,629 m^3 (~11,050 to 16,500 yd^3).

As long as the CoC exceed baseline concentrations, injury to microbial processes will continue to occur and at the lower concentrations may contribute to subtle effects in vegetation. Continued exceedence of the system-specific phytotoxicity threshold will be manifest as overt injuries including decreased productivity, reduced root growth, decreased survival, and altered community composition. Individually, and collectively, these effects diminish the aesthetic and ecological character of the landscape and prevent the Department of the Interior from fully achieving its Congressional mandate.

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ABBREVIATIONS

μg .... microgram
μmol .... micromole
ARAR(s) .... Applicable, or Relevant and Appropriate Requirements
As .... arsenic
BLM .... Bureau of Land Management
BPQL .... Below Probable Quantitative Limit
C .... Celsius
Cd .... cadmium
C.F.R. .... Code of Federal Regulations
CERCLA .... Comprehensive Environmental Response, Compensation, and Liability Act
CFR .... Clark Fork River
cm .... centimeter
CoC .... Constituent(s) of Concern
Cu .... copper
DOI .... Department of the Interior
Eh .. a measure of Redox equilibria, millivolt difference between Pt and standard H electrodes
ep and **t** .... **e**cological **p**lanning and **t**oxicology, inc.
FR .... Federal Regulations
g .... gram
GRKO .... Grant-Kohrs Ranch National Historic Site
km .... kilometer
mm .... millimeter
NPS .... National Park Service
NRDA .... Natural Resource Damage Assessment
OU .... Operable Unit
PAR .... Photosynthetically Active Radiation
Pb .... lead
PC .... Principal component
pH .... negative log of hydrogen ion concentration
PLFA .... Phospholipid Fatty Acid
ppb .... parts per billion
ppm .... parts per million
PQL .... Probable Quantitative Limit
RAR(s) .... Relevant, and Applicable Regulation(s)
QA .... Quality Assurance
QC .... Quality Control
RH .... Relative Humidity
ROD .... Record of Decision
s .... second
USDA .... U.S. Department of Agriculture
Zn .... zinc

1 INTRODUCTION

Large-scale mining activities in the vicinities of Butte and Anaconda, MT, began in 1884 (Tetra Tech, 1987). Until the closure of the Washoe Smelter near Anaconda in 1980, contaminants were deposited via wetfall and dryfall onto surrounding lands, but primarily in a northerly direction. Surface soil concentrations of contaminants have been reported to exceed baseline levels in a northeasterly direction at least as far as Deer Lodge, Montana, (Lipton *et al*., 1993; Munshower, 1972, 1977; Taskey, 1972). Mining wastes were deposited, re-entrained, and re-deposited along the banks and in the floodplain along Silver Bow Creek and the Upper Clark Fork River.

The major constituents of concern (CoC) include arsenic (As), copper (Cu), cadmium (Cd), lead (Pb), zinc (Zn), and acid generating materials. The impacted areas from Butte to Milltown and Anaconda to Warm Springs were placed on the National Priority List (a.k.a., Superfund Sites) in 1983. The National Park Service's Grant-Kohrs Ranch National Historic Site (GRKO), near Deer Lodge, Montana is located within the boundaries of the Clark Fork River Operable Unit (CFROU; Figure 1).

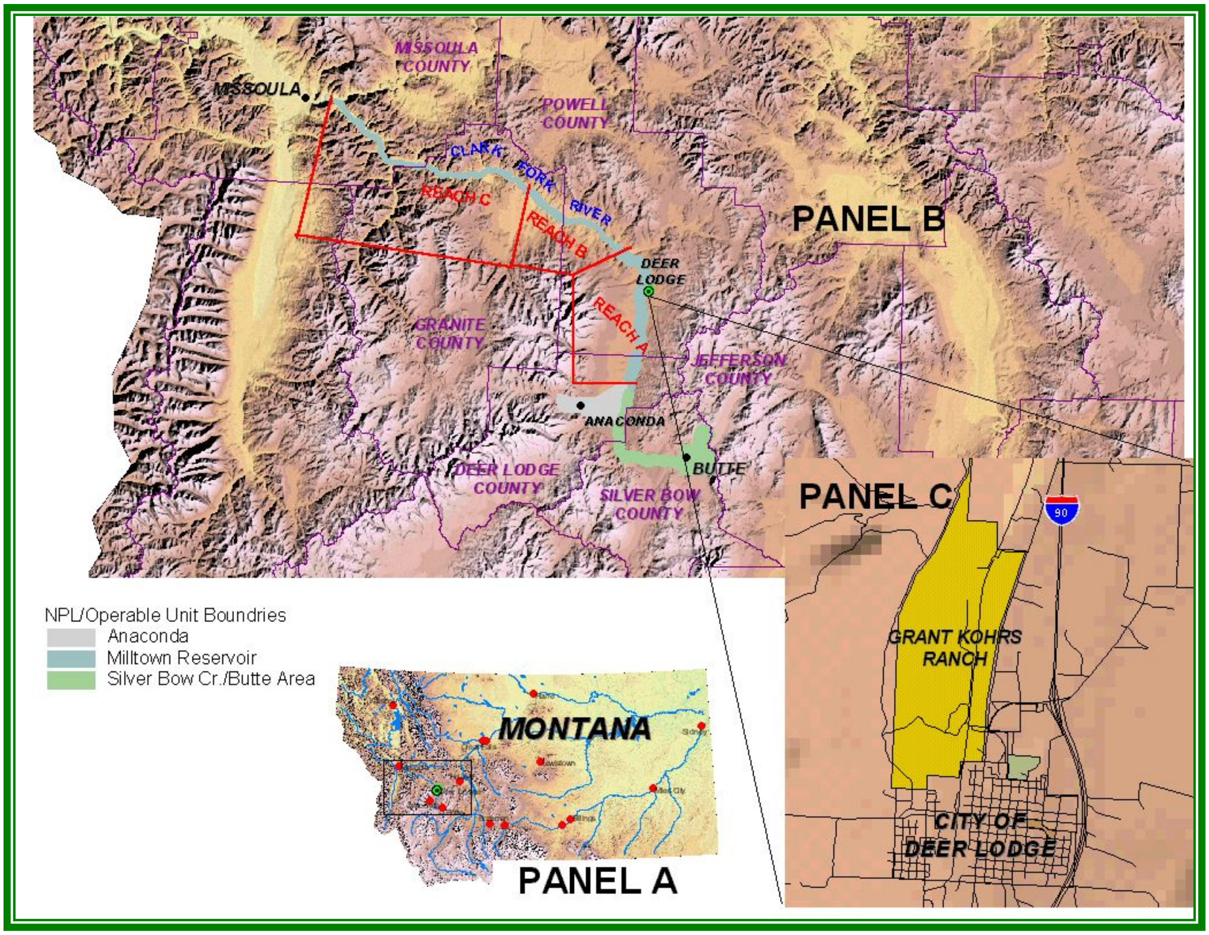

Figure 1. Location of GRKO in relation to the Clark Fork River Operable Unit Reaches A, B, and C, Clark Fork Valley, MT addressed in this injury assessment.

The legislative boundary of the GRKO (Figure 2) is comprised of 654.8 ha (1,618 ac). This includes approximately 51 ha (126.1 ac) of fenced riparian zone largely within a 54.4 ha (134.5 ac) the active floodplain.[1] There are 187.4 ha (463 ac) contained within the 100-year floodplain. Historically irrigated fields comprise 229.1 ha (566 ac). There are 97.9 ha (242 ac) of non-irrigated uplands.

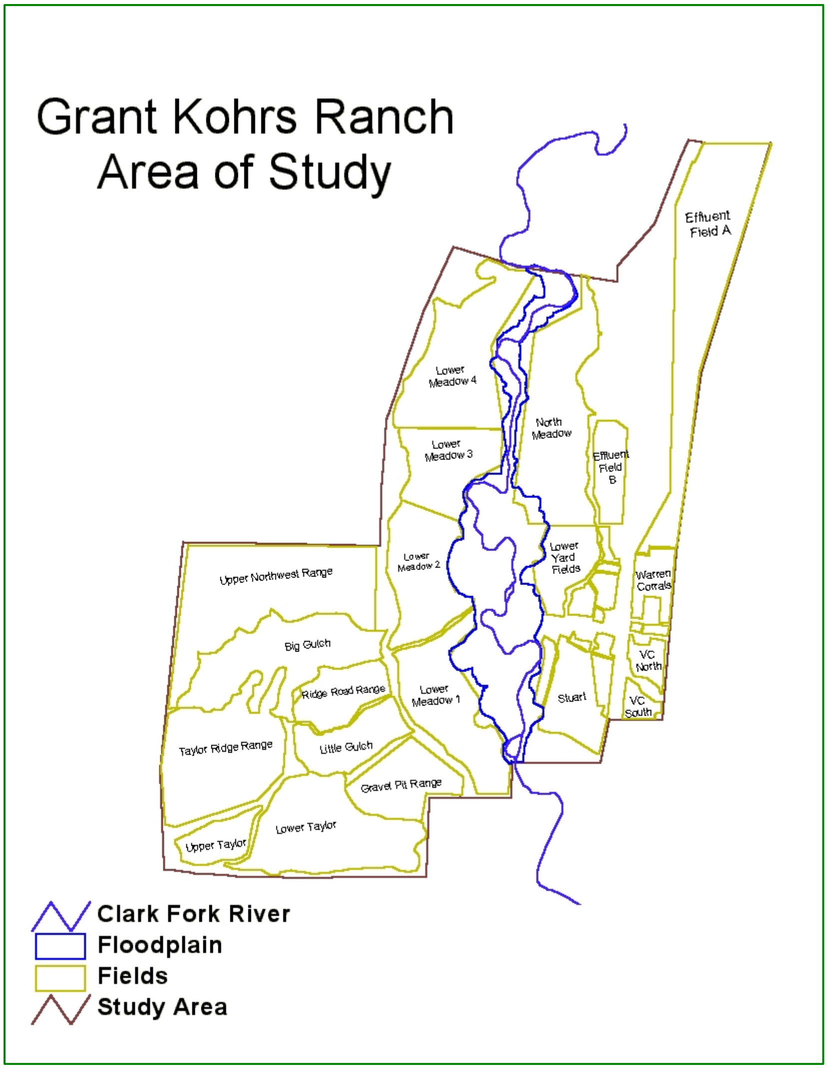

Figure 2. Delineation of fields, floodplain, and the riparian corridor of the GRKO.

The Organic Act of 1916 [16 U.S.C. Section 1 *et seq*. (1916)] established the National Park Service within the Department of the Interior, stating that:

> "The service…shall promote and regulate the use of the Federal areas known as national parks, monuments, and reservation … which purpose is to conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations."

[1] N.B. All areas are approximate, as the units were not surveyed. Small segments of the fenced riparian area are outside the active floodplain and other small segments of the active floodplain are outside the fenced area.

And Congress established the Grant-Kohrs Ranch National Historic Site [Pub. L. 92-406, 86 Stat. 7632 (1972)],

> "…to provide an understanding of the frontier cattle era of the Nation's history, to preserve the Grant-Kohrs Ranch, and to interpret the nationally significant values thereof for the benefit and inspiration of the present and future generations."

1.1 IDENTIFICATION OF SERVICES

The uniqueness of GRKO is attributed to the quality and extent of the cultural landscape that provides the visual and ecological context of the ranch's history. The riparian area, wet meadows, and grasslands, which furnish the backdrop for the historical interpretation so integral to the mission of GRKO, have changed slightly since the late 1800s due to normal ranching activities. However, the essential features of the riparian corridor, historically irrigated fields, and non-irrigated uplands of this cultural landscape have been adversely affected by mining wastes.

A 1987 analysis of the cultural landscape reinforces this point:

> "…the various land and vegetation types related to the ranch's operation…provides the scene necessary to maintain the ranch's historic integrity, while providing a resource base necessary for public understanding and interpretation of the western cattle frontier…Thick woodlands and semi-wetlands are located throughout riparian areas associated with the river floodplain. The woodlands remained relatively intact until mine tailings from upstream mining activities killed some of the vegetation…Views to the north and west convey the wide-open spaces and sense of isolation associated with early operations of the ranch…The ranch and landscape within the study area possess historic landscape significance on local and regional levels."[2]

And also;

> 'The landscape…is significantly related to the ranch complex. Maintaining this scene is critical if the National Park Service is to achieve the Congressional mandate to "provide and understanding of the frontier cattle era of the Nation's history." (*Cultural Landscape Analysis*, pg. 31)

Historically, the riparian area served as important wildlife habitat for many species of birds and animals. Its complex of wetlands, riparian vegetation, and tributary system provided an important and varied habitat for aquatic organisms. And the woody vegetation provided shelter for wildlife and cattle, particularly during winter calving season.

The services provided by the natural resources of the GRKO are both tangible and intangible; they are derived from an array of complex, natural plant communities. Riparian communities normally are established and maintained in response to episodic disturbances and relatively quiescent periods in what may be viewed as a dynamic landscape. That is, normal change following disturbance events such as flooding result in a mix of early-, intermediate-, and late-successional communities. Landscapes of this nature, if free of toxic substances, also permit modest extraction of plant productivity through grazing or haying operations in a sustainable fashion. The tangible and intangible services required of the natural resources of the GRKO emanate from soils free of hazardous substances above toxic thresholds. These are

1. complex, natural plant communities that follow normal successional trajectories;
2. microbial communities that achieve nominal rates of mineralization;

[2] *Cultural Landscape Analysis*: Grant-Kohrs Ranch National Historic Site. Rocky Mountain Region, National Park Service. June 1987

3. normal levels of productivity within the natural and agricultural areas;
4. streambanks exhibiting normal levels of stability against erosion;
5. vistas with aesthetic qualities that portray the visual diversity of vegetative form and structure (trees, shrubs, meadows) typical of the early ranching period; and
6. opportunities for educational experiences in ecology, geology, ranching, arts (visual, performing, literary, etc.), and culture pertaining to the early ranching period.

1.2 QUANTIFICATION OF SERVICE REDUCTION

The reduction in services resulting from injury to natural resources on DOI lands will be quantified in the Damage Assessment Report that will be produced later.

1.3 INJURY ASSESSMENT OVERVIEW

Provisions under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) provide a framework for cleanup of hazardous substances and compensation for damage to natural resources resulting from the release or threatened release of hazardous substances. Guidelines for demonstrating injury and calculating damages [Natural Resource Damage Assessment (NRDA)] for loss of services due to injury to natural resources were established by the Department of the Interior (DOI) as published in the Code of Federal Regulations (43 C.F.R. Part 11). *Injury* is defined as “measurable adverse change, either long- or short-term, in the chemical or physical quality, or the viability of a natural resource resulting either directly or indirectly from exposure to a release of a hazardous substance, or exposure to a product of reactions resulting from the release of a hazardous substance” [43 C.F.R. § 11.14 (v)]. Regulations also provide for identification and evaluation of completeness of resource exposure pathways involving hazardous substances, which may injure natural resources [43 C.F.R. § 11.63]. *Pathway Determination* may be accomplished by the “demonstration of sufficient concentrations in the pathway for it to have carried the substance to the injured resources” [51 FR 27685]. *Injury Quantification* is a measure of the effects of the releases of hazardous substances in terms of changes from *baseline conditions* [43 C.F.R. § 11.70 (a)]. In the injury quantification phase, the extent of injury is evaluated relative to baseline conditions and the ability of the resource to recover [43 C.F.R. § 11.71 (b)]. Baseline conditions are those conditions that “would have existed at the assessment area had the … release of the hazardous substance … not occurred” [43 C.F.R. § 11.14 (e)] and the conditions to which the injured natural resources should be restored [43 C.F.R. § 11.14 (ll)]. In defining the baseline conditions, both natural processes and human activities within the normal range of physical, chemical, or biological conditions for the assessment area are considered [43 C.F.R. § 11.72 (b)].

The DOI has trusteeship for natural resources of DOI holdings. For more than a century, the natural resources on these lands have been injured due to exposure to hazardous substances from up stream mining activities. Releases continue today to the detriment of these trust resources. This Natural Resource Injury Report documents the magnitude of injury to natural resources and provides the basis for calculating compensable damages. The foundation and schedule for the current effort was embodied in the *Streamside Tailings Operable Unit and Federal and Tribal Natural Resource Damage Consent Decree* that was approved by Judge Paul Hatfield (19 April 1999). This report draws heavily on findings of fact developed in reports prepared for various phases of work associated with the CFROU, and as such incorporates those findings by reference (e.g., Canonie, 1992; CH2M Hill, *et al.*, 1991; Lipton *et al,* 1993; PTI, 1989; ISSI, 1999; Montana State University, *et al.*, 1989a,b; MultiTech, 1987; TetraTech, 1987). The methods used in this phase of work specific to determining injury to NPS lands conform to criteria of a modified Type B Natural Resource Damage Assessment (NRDA) following the guidance contained in 43 C.F.R. Part 11.

The National Park Service Organic Act and the Grant-Kohrs Ranch enabling legislation, both quoted above, establish the guiding principles by which GRKO is to be managed in perpetuity. Embedded in these statutes is the congressional mandate to protect tangible and intangible ecological services derived from the natural resources of the lands. The tangible or material resources of note are the ecological, geological, hydrological, and cultural features of the landscape. Intangible or derived resources include aesthetic and scenic opportunities, as well as interpretations of historical and cultural uses of these resources.

The enabling legislation directs the Secretary of the Interior in establishing and managing the GRKO "to provide an understanding of the frontier cattle era of the Nation's history, to preserve the Grant-Kohrs Ranch, and to interpret the nationally significant values thereof for the benefit and inspiration of present and future generations." In recognizing these special conditions, the US EPA itemized five specific elements considered as Relevant and Appropriate Requirement(s) for use in selecting remedies under CERCLA:

1. Re-establish the historic landscape conditions in the Riparian/Woodland Cultural Landscape area, which were present during the frontier cattle era. This requires conditions sufficiently free of contaminants to support natural reestablishment of self-reproducing and sustaining native riparian vegetation communities of the types that would be present except for the effects of hazardous substances.

2. Assure the natural reestablishment of diverse native riparian vegetation communities and other tangible and intangible resources. Tangible resources include biological, geological, hydrological, and cultural resources such as historic structures, landscapes, and artifacts. Intangible resources include scenic vistas, solitude, and visitor appreciation of sight themes, historic setting, and their contexts.
3. Reduce contamination in the riparian areas to ensure that hazards to livestock, vegetation, and wildlife, as well as humans, who visit the site or work there, do not present unacceptable risks.
4. Reduce to acceptable levels of risk the potential for future releases of hazardous substances from upstream sources, and likewise from the Grant-Kohrs Ranch property to areas downstream.
5. Assure protection of the floodplain and historically irrigated lands within the boundaries of the park unit.

Ecological systems are inherently complex. Multiple abiotic and biotic components interact over time resulting in self-regulating collections of species and processes. Proper functioning of ecological systems depends on the flow and cycling of nutrient among various compartments (e.g., soil, microbes, soil invertebrates, plants, macroinvertebrates). Humans rely on ecological systems to provide tangible or material resources such as food and fiber, and intangible or derived resources such as spiritual, cultural, aesthetic, and educational experiences.

These attributes of the natural resources serve as guides to determine injury. Relationships among contaminants and natural resources (e.g., CoC impacts on microbial process and plants) are described later in this Injury Report (see Chapter 3. Geologic Resources -- Riparian and Upland Soil).

1.4 PRIOR WORK

At least 22 different studies or reports related to DOI lands have been completed since 1984 (Appendix A). These have included descriptions of vegetation characteristic of contaminated zones, CoC levels, phytotoxic responses, soil invertebrate toxicity responses, and potential contamination of livestock. Four early studies related plant community relationships to levels of contaminants (Rice *et al.*, 1984; Ray, 1984, 1985; and Rice and Ray, 1985). These showed that:

- As, Cu, and Cd levels in meadows and haylands were elevated;
- microbial enzyme activity levels were greatly depressed in slickens areas;
- acute phytotoxicity was evident in slickens;
- metal levels in shoots of redtop were elevated compared to controls; and

- depression of plant community coverage and species richness along transects corresponded closely with the solubility of copper and cadmium.

The authors suggested that species in the plant communities are apparently dispersed according to differential metal tolerances. These studies and the concerns they raised related to health risks and exposure to tailings material were important in the decision to restrict grazing in the riparian zone in 1994 (Foster, 1994).

Rader (1995) conducted a series of studies of phytotoxicity and soil invertebrate toxicity using tailings from the GRKO. He observed that the phytotoxicity was related to pH effects on metal concentrations and that root growth was the most sensitive endpoint.

Several reports indicated that mammals were not exposed to toxic levels of CoC. Moreover, accumulation of CoC in the tissues of livestock was sufficiently low as not to pose unacceptable risk to humans (or most likely to other omnivores or carnivores) but did result in CoC concentrations two to three times that normally found in beef cattle.

While the quantity of prior work was considerable, the studies were not designed to characterize injury under the DOI guidelines. Therefore, the recent investigations carried out during the 2000 and 2001 field seasons were conducted to build upon these basic findings.

1.5 REPORT ORGANIZATION

The components of ecological systems interact dynamically. The services provided by properly functioning ecological systems are dependent on a variety of complex interactions between abiotic and biotic components. Despite the nature of the interconnections, evaluation of injury resulting from the releases of hazardous substances requires discrete analyses of components and processes. Both the scientific approach and the legal framework for injury determination dictate assessment of individual resources and a weight-of-evidence interpretation of the assembled information. This report, which assesses injury to natural resources under the responsibility of the National Park Service along the Clark Fork River, is presented in three chapters.

Chapter 1, Introduction (page 1) provides an overview of the environmental framework, prior work on the DOI lands, and legal framework under which the injury determination was developed.

Chapter 2, Sources and Pathways of Hazardous Substances (page 8) addresses the pathway of CoC mobility as a critical continuing release of hazardous substances affecting soils and vegetation. In particular, it:

- describes the historical and contemporary facts regarding the initial contamination of DOI lands from mining activities;
- summarizes physical and chemical processes that result in continuing releases of hazardous substances;
- presents the conceptual model depicting relationships among physical, chemical, and biological processes that result in exposure to valued biological resources and the services derived therefrom, is also presented; and
- characterizes soilwater and groundwater movement of CoC from soil into pore water and ground water.

Chapter 3, Geologic Resources -- Riparian and Upland Soil (page 25), describes injury to geologic resources in riparian and upland soils due to contamination from mining activities. Following a description of the soil resources and operable definitions of injury, quantitative determinations of baseline CoC concentrations and the evidence for elevated levels of CoC are presented, as are baseline vegetation patterns. Results of phytotoxicity tests, microbial respiration measurements, microbial community structure, and measures of plant production are interpreted in relation to the levels of CoC. These biological responses were used to define critical concentrations above baseline concentrations to delineate the areal extent and volume of injured soils. Existing vegetation patterns and the ability of the riparian and upland soil resources to recover from the injury are discussed. This chapter concludes with a weight-of-evidence analysis, a summary of the suite of data and analyses and establishes the magnitude of injury. This chapter presents the opinions reached individually and collectively by the principal investigators whose work has contributed to the findings described in this report.

References Cited (page 72) lists the full citation of books, scientific articles, published reports, and unpublished reports referred to in this injury assessment.

Appendix A. Annotation of Prior Studies is a separate document providing an overview of various studies conducted since 1984 on DOI lands.

Appendix B. Compilation of predominant species in baseline type communities is a separate document providing a list of prominent species (>1% composition) of 16 type communities for the riparian corridor of GRKO.

Appendix C. Cross-list of surface soil sample codes is a separate document providing codes used to identify samples in different studies performed in 2000 and 2001.

2 SOURCES AND PATHWAYS OF HAZARDOUS SUBSTANCES

Pathway determination was used to establish the route of transport of hazardous substances from their sources to the natural resources [43 C.F.R. § 11.63 (b) and (c)]. Two primary sources of hazardous substances from mining operations were considered in the evaluation of pathways affecting natural resources on DOI lands (Figure 3). Mining wastes deposited along watercourses in the upper reaches of Silver Bow Creek have been transported downstream and into the Clark Fork River. Water diverted from the Clark Fork River for irrigation of the GRKO provided a source of waterborne contaminants to pasturelands and meadows of the lower upland areas of the GRKO. Smelter emissions from operations at Anaconda have deposited contaminants over vast areas, resulting in elevated soil levels at least as far as Deer Lodge to the northeast. Negligible levels were deposited farther northeast via air transport from the smelter. Because the two sources involve fundamentally distinct pathways of exposure, we have presented the information on sources and pathways separately in this Chapter (2.1 Floodplain and Stream Bank Pathway Determination, page 8 and 2.2. Uplands Pathway Determination, page 13).

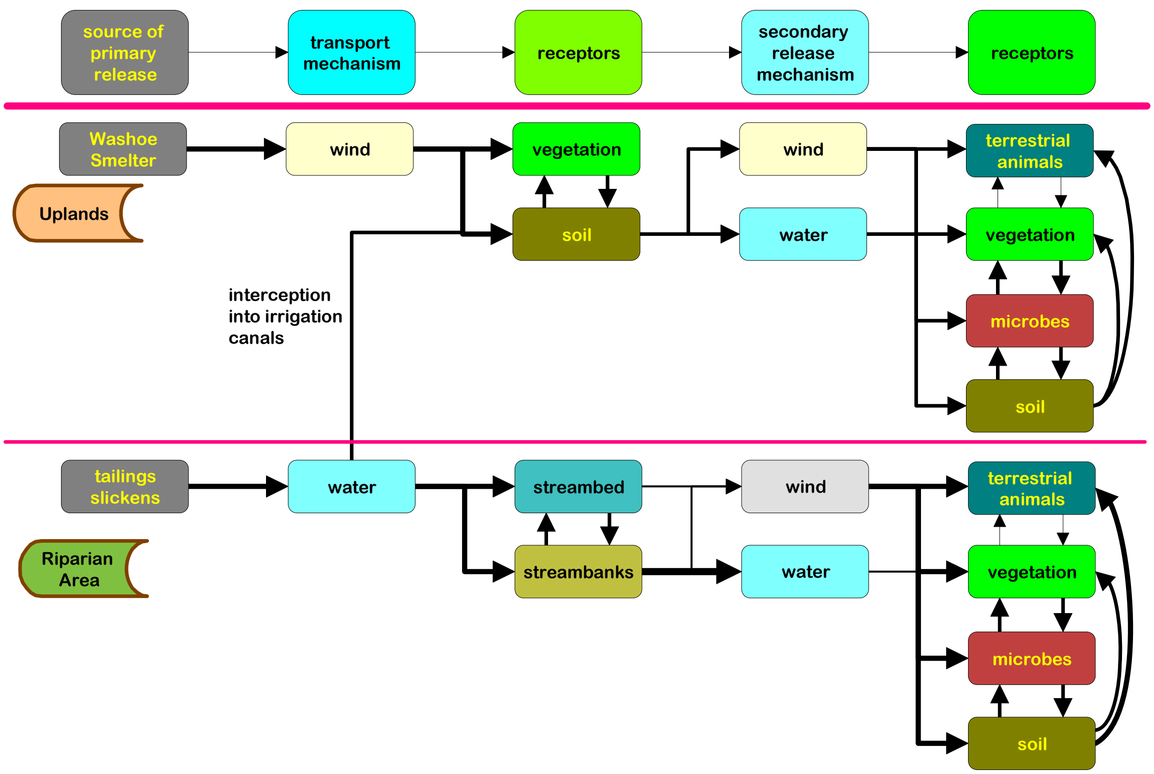

Figure 3. Generalized pathways from sources of hazardous substances to exposure of natural resources of the DOI lands.

2.1 FLOODPLAIN AND STREAM BANK PATHWAY DETERMINATION

This sub-section discusses sources, transport, and extent of contamination of the riparian resources of the DOI lands within the CFROU. Transport includes long distance movement of sediments and migration of soluble fractions in the soil column.

The riparian resources of the DOI have been subjected to deposits of hazardous substances from mining operations originating in several locations along Silver Bow Creek (Table 1). Though mining operations ceased in the early 1980s, re-release of tailings deposits continues. Elevated levels of

CoC in the riparian soils and streambanks on the DOI lands include As, Cd, Cu, Pb, and Zn and are distinguishable from baseline (i.e., non-contaminated) levels of these same substances. Patterns of CoC are similar to those of tailings deposits upstream nearer the points of CoC origin.

Table 1. Sources of hazardous substances deposited in and along Silver Bow Creek. [This table is reproduced from Table 5.1 of Lipton *et al.* (1993).]
<u>Historical discharge of raw mining and mineral-processing wastes directly into Silver Bow Creek</u> • Occurred from the inception of mining in the Butte area, approximately 1878, until 1976, when the Weed Concentrator treatment process was expanded to include mill wastewater (MultiTech, 1987a). • Tailings, waste rock, smelter slag, process water, and mine-water were discharged directly to Silver Bow Creek (MultiTech, 1987a).
<u>Smelting Waste Deposits</u> • At least six major smelters were built along Silver Bow Creek between 1879 and 1885 between Meaderville and Williamsburg (Historical Research Associates, 1983; Meinzer, 1914; Freeman, 1900; Smith, 1952; all as cited in MultiTech, 1987a). • Smelters operated continuously until 1920 (except for the Pittsmont Smelter, that operated until 1930). • Tailings and slag waste products were deposited on the Silver Bow Creek floodplain or sluiced to tributaries of Silver Bow Creek (CH2M Hill and Chen Norther, 1990; Flynn, 1937 as cited in MultiTech, 1987a).
<u>Waste Rock Deposits</u> • Waste rock dumps identified in the Butte area include: the Belmont and other inactive mines; waste rock dumps in the Warren Avenue drainage basin; numerous inactive mines and associated waste dumps located outside the MRI boundary fence; eroded mine wastes in the Anaconda Road-Butte Brewery Basin; heavily eroded waste rock dumps in Buffalo Gulch Basin; and waste rock dumps in Missoula Gulch (Camp Dresser and McKee, 1991).
<u>Tailings Deposits</u> • Tailings deposits, which have been identified as significant sources of hazardous substances, include the Parrot Smelter Tailings, the Butte Reduction Works tailings, and the Colorado Tailings. • Historically, tailings were deposited on the Silver Bow Creek floodplain. Photographs (1955) show extensive exposed tailings and slag deposits in the upper Metro Storm Drain area (CH2M Hill and Chen Northern, 1990). • An estimated 3.7 to 7.8 million cubic yards of contaminated tailings and waste materials have been deposited along the Silver Bow Creek floodplain and serve as sources of re-released hazardous substances (Canonie, 1992).

2.1.1 Transport Pathway Identification – Particle Transport

An estimated 3.7 to 7.8 million cubic yards of contaminated tailings and waste materials were deposited along the Silver Bow Creek floodplain (Canonie, 1992; see Table 1). These deposits continue to be sources of re-released hazardous substances. The large quantities of materials discharged into Silver Bow Creek filled much of the channel of Silver Bow Creek, which in turn caused increased flooding frequency and accelerated river meandering as the increased sediment load clogged the channel (GCM Services, Inc., 1983 as cited in MultiTech 1987a). Because of clogged channels, a braided stream pattern developed and progressed downstream (Smith *et al.*, 1998).

Exposed tailings, waste rock piles, contaminated soils, and large expanses of exposed streamside tailings along Silver Bow Creek are subject to erosion and entrainment during high water, snowmelt, and precipitation-induced runoff (CH2M Hill and Chen Northern, 1990). Streams at high water stage carry increased suspended sediment loads and, as high waters recede, the sediment load is deposited on the floodplains.

The record flood of 1908 was responsible for substantial portions of tailings material being transported onto DOI lands. That and earlier floods have resulted in elevating portions of the floodplain above historical levels. Also, later deposition events have resulted in buried tailings (i.e., tailings overlain with relatively uncontaminated fluvial deposits). Fluvial processes associated with the erosion-deposition cycle of tailings have created a heterogeneous distribution of CoC in the riparian zones, especially downstream of Warm Springs Ponds. Tailings with highly elevated concentrations of Cu and other CoC are exposed at the surface in numerous places in the floodplain. They also occur buried under varying thicknesses of relatively uncontaminated riparian soils (Figure 4).

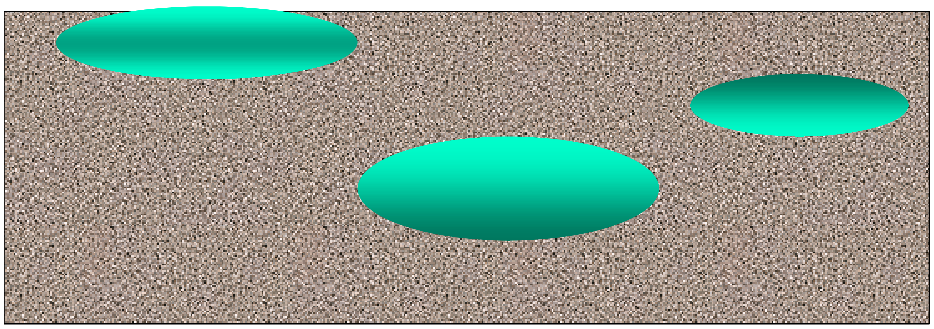

Figure 4. Simplified conceptual depiction of exposed and buried tailings [greenish lenses], which occur in otherwise relatively uncontaminated riparian soils on the DOI lands.

2.1.2 Transport Pathway Identification – Solution Transport

Water is an excellent solvent. Consequently, substances on and in soil come into solution under certain conditions and precipitate out of solution under other conditions. The dynamic movements of water into and through soils presents opportunity for transfer of contaminants from soils to water. Precipitation or irrigation water flowing onto the soil surface generally percolates through soils and recharges groundwater supplies. In general, groundwater in the area tends to be discharged to surface waters as springs or pumped to supply drinking water for humans or livestock, or for irrigation. Where groundwater is near the surface, it can move upward through the soil profile; and upon reaching the surface it will evaporate, leaving dissolved substances on the surface. Plants also draw substantial volumes of water from the soil water fraction. Many plant species tap groundwater sources as well.

Baseline concentrations of As, Cd, Cu, and Zn were calculated for both vadose zone (pore water) and groundwater (Moore and Woessner, 2001; Woessner and Johnson, 2002). Baseline for Pb in groundwater was not established because nearly all samples had concentrations below the detection limit. To calculate background concentrations for groundwater, wells were selected that were located outside (up gradient) of the area of tailings contamination. Soil water recharge was considered to become groundwater via downward percolation, thus groundwater baseline values were used as the soil water baseline. This provided very conservative baseline concentrations for soil pore water due to the dissolution and mobilization of CoC-free precipitation, with concentrations increasing with percolation toward the groundwater table.

Baseline concentrations were calculated by taking the median concentration of samples collected at all sampling times and depths for an individual site. The CoC baseline concentrations (Table 2) were defined to be the median of the median values calculated for individual sites. Samples with concentrations below the instrument detection limit (PQL) were assigned the PQL.

Table 2. Groundwater baseline concentrations (ppm) for As, Cd, Cu, and Zn from wells located on or near the GRKO.

CoC	Median of Medians [a]	MAD [b]	Maximum	Minimum	N
As	0.005	0.0000	0.005	0.005	10
Cd	0.001	0.0000	0.001	0.001	10
Cu	0.003	0.0000	0.003	0.003	10
Zn	0.00225	0.00025	0.002	0.004	10

[a] Baseline are the median concentrations of all wells.

[b] Median absolute deviation

Eleven groundwater-monitoring wells and nine multi-level piezometers were installed across the GRKO [See Plate 3 of Moore and Woessner (2001) for location of wells]. Nineteen sets of soil water monitoring instruments were installed. Each of these sets consisted of two or three nested tensiometers and suction lysimeters. Tensiometers were installed at depths of 6, 12, and 24 inches below land surface. Suction lysimeters were installed at approximately 25 cm (10 in), 50 cm (20 in), and 75 cm (30 in). Tensiometers were used to measure soil matrix potential (to characterize the vertical movement of water through the soil), while suction lysimeters were employed to facilitate the collection of soil pore water for chemical analysis. Groundwater and soil pore water samples were collected and water level measurements and tensiometer readings were recorded periodically throughout the months of May 2000 through September 2001. Water levels were measured in the monitoring wells. In addition to the instruments installed during the year 2000 field season, five extant monitoring wells associated with fields being irrigated with secondary effluent were incorporated into the well network.

Groundwater occurs near the ground surface at GRKO. The water table is within about 1.5 m (5 ft) of land surface in the floodplain portion of the site; 3 to 6 m (10 to 20 ft) below land surface under the gravel terraces to the east, and as deep as 10 m (30+ ft.) below land surface in the upper parts of the west side fields. Contours of the water table in June 2000 (See Figure 12 in Moore and Woessner, 2001) and December 2000 (See Figure 13 in Moore and Woessner, 2001) show the groundwater system slopes towards the Clark Fork River. Groundwater flow is from the uplands to the floodplain area, requiring approximately 3,000 to 8,000 days to move from the GRKO outer boundary to the Clark Fork River.

Deer Lodge and surrounding areas typically have a moisture deficit, (i.e., evapotranspiration potential exceeds precipitation levels; Moore and Woessner, 2001). Tensiometer readings generally indicated more negative matrix potentials at the shallow measuring sites (15 cm; 6 in; See Figure 14 and Figure 15 in Moore and Woessner, 2001). In addition, the soil matrix potential became more negative as the summer and fall progressed, indicating continued drying of the soil. Movement of soil water generally was toward the land surface. Consequently, there are strong physical forces acting to "wick" soluble salts to the surface. It is common along the upper reaches of the Clark Fork River, including areas on the GRKO, to find salt crystals bearing hazardous substances at the soil surface. The crusts formed on the surface are readily soluble in water. Hence, even with light precipitation, the hazardous substances become mobilized into surface runoff or infiltrate into the surficial soil water compartment. With heavier precipitation events, the dissolved hazardous substances percolate into the groundwater compartment. Reddish-colored puddles were observed on the west side of the Clark Fork River while conducting field sampling in the summer of 2000. Chemical analyses of water samples from such puddles established that substantial concentrations of CoC occur episodically. Mean concentrations of five samples showed As at 164 ppb; Cd, 4.4 ppb; Cu, 163 ppb; and Zn 155 ppb in the ephemeral pools.[3] These values are 10-, 26-, 5-, and 4-times greater than mean values reported from Clark Fork River water at the USGS Deer Lodge gauging station.[4] The concentrations measured in these puddles are indicative of the rapid and substantial mobilization of CoC by rainwater running over and through surface soils. Given the location of the puddles above the floodplain and away from irrigation flow, the source of the contaminants is the accumulated smelter fallout and contaminated irrigation water and sediments originating from the Clark Fork River.

Median CoC concentrations of water samples from all depths and all collection times were determined for each site. Arsenic levels exceeded 2-times baseline in seven wells, with one of these >10-times baseline; Cu levels exceeded 2-times baseline in four wells; and Zn levels exceeded 2-times baseline in six wells with three wells having levels >10-times baseline. The majority of the riparian corridor and the west fields had elevated levels of one or more CoC in groundwater (See Figure 25 in Moore and Woessner, 2001). Similarly, soil water concentrations measured from lysimeters showed markedly elevated concentrations of As, Cd, Cu, and Zn. The majority of the soil water in the riparian corridor and all of the irrigated east fields had elevated levels (i.e., >2-times baseline) of one or more CoC (See Figure 26 in Moore and Woessner, 2001).

Groundwater depth, both in the floodplain and in the fields, was determined from lysimeter and well data.[5] The impacted area, mean depth below ground surface of contaminated soil water, and standard porosity of the soil were used to calculate the volume of contaminated water. The total volume of contaminated water on the GRKO was calculated to be 1,940,450 m^3, comprised of 87,750 m^3 of soil water and 1,852,700 m^3 of ground water.

2.1.3 Contamination Pathway

Slickens deposits are often identifiable as barren areas lacking vegetation. Some metal-tolerant species such as tufted hairgrass (*Deschampsia cespitosa*) may become established along the margins of slickens. Vegetation occupying shallow lenses of uncontaminated soil overlaying buried tailings is typically stunted or dying. Such areas (barren slickens or buried tailings with poorly established vegetation) lack the deep soil-binding roots and likely contribute to stream bank failure. Even modest rises in stream energy undercut shallow-rooted areas resulting in slumping of the surface and underlying materials into the stream channel. Such slumping creates a continual threat that additional contamination will be released to the floodplain of the DOI lands as such events occur upstream of these lands. Stream bank erosion eliminates or threatens natural resources on the DOI lands. The dynamic interactions of physical forces, including erosion (Figure 5 panel A and B), leaching or percolation (Figure 5 panel B) moving CoC deeper into the soil profile, and wicking (Figure 5 panel C) of soluble contaminants to the surface result in continuing and recurring cycles of exposure. Hazardous substances from these tailings have been transported at least as far as the Milltown Reservoir (nearly 200 km downstream of the GRKO). Reworking of the soil surface, primarily during flooding events, exposes buried tailings. Animals may also expose buried tailings as they burrow (small mammals, bank swallows, and other birds) or their feet sink into soft, wet soils (large mammals) as they traverse riparian areas.

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[3] These data were reported by Ms Clara Wheeler, Research Specialist, Department of Geology, University of Montana in an email to Mr. Greg Nottingham (GRKO) dated 04/09/2001.

[4] Summary data compiled by Mr. Greg Nottingham, GRKO, supplied on 02/08/2002.

[5] For detailed explanation of procedures to calculate volume of contaminated soil water and ground water see Woessner and Johnson (2002).

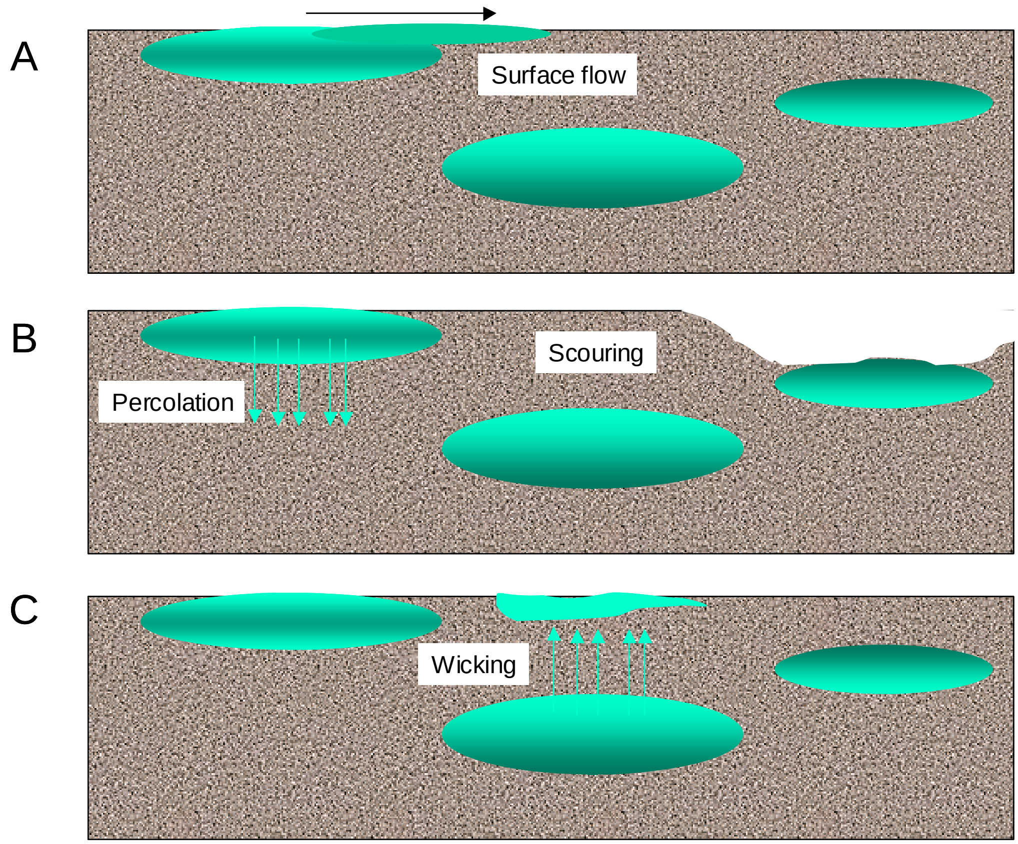

Figure 5. Conceptual Model depicting dynamics in the floodplain of the DOI lands resulting in exposing new tailings surfaces.

2.2 UPLANDS PATHWAY DETERMINATION

Contamination of upland areas occurred primarily from aerial deposition of smelter emissions during the late 19th and early 20th Century (Lipton, *et al*., 1995). Prevailing winds distributed CoC primarily in a northeasterly direction from the smelters (Munshower, 1972, 1977; Taskey, 1972). During dry periods in summer, wind erosion retrains surficial deposits. Snowmelt and surface flow during hard rains also results in continuing releases of contaminants. Hazardous substances in surficial deposits may be mobilized across the soil surface and percolate through the soil. This occurs in irrigated fields as well as throughout the floodplain. When saturating conditions occur, percolation of contaminants may reach groundwater.

2.2.1 Source Identification

Documentation of historical smelter emissions and measured levels of CoC in soils resulting from aerial deposition of smelter emissions (Lipton *et al*., 1993) established the source of these hazardous substances as the Washoe Smelter. Localities near the smelter had markedly higher surficial soil concentrations compared to areas farther from the smelter (see Figures 2-5 through 2-9 in Lipton *et al*., 1993). Surficial soils (0 to 5 cm; 0 to 2 in.) had higher CoC concentrations than soils deeper in the profile, consistent with aerial deposition (Moore *et al*., 2001).

Smelting and ore refining began in the Anaconda area in 1884 (TetraTech, 1987) and continued until closure of the Anaconda smelter in 1980. During those 96 years, ARCO and its predecessors were responsible for the release of massive quantities of CoC. Daily releases measured in 1907 were 29.6

tons of arsenic trioxide, 2.2 tons of copper, 2.4 tons of lead, and 3.0 tons of zinc (Harkins and Swain, 1907). Mean arsenic discharge from the smelter for the period from 1911 to 1916 were reported as 40 to 62 tons per day (Anaconda Smelter Smoke commission, as cited in Taskey, 1972). Estimates of arsenic emissions for the period of 1914 to 1918 were 75 tons per day (Wells, 1920 as cited by Taskey, 1972). Even as late as 1962, the town of Anaconda had ambient arsenic concentrations among the highest in the country at 0.45 µg m^{-3} (Montana State Board of Health, 1962, as cited in Taskey, 1972). Stack emissions reported for the month of October 1976[6] included Cu, 160 tons; Pb, 55 tons; Zn, 67 tons; As, 190 tons; and Cd, 5 tons.

Constituents of Concern are released from air-fall contaminated soils by natural recharge, irrigation in the western and eastern fields, and by recharge to the contaminated floodplain soils. Some contaminants are also present in the irrigation water that originates from the Clark Fork River.

2.2.2 Transport Pathway Identification

Transport was most pronounced in the northeasterly quadrant, (i.e., toward Deer Lodge). Characterization was extended only to Deer Lodge. Though the levels at Deer Lodge were approximately two orders of magnitude lower than those near the source, nevertheless the measured concentrations were discernibly higher than baseline concentrations.

Contaminant releases continue to occur through wind erosion and precipitation events. Contaminated surficial soils are subject to relatively high rates of wind erosion, particularly during dry summer periods. These fugitive emissions are most pronounced in areas devoid of vegetation. Rainwater, snowmelt, or irrigation water provides additional re-release mechanisms. Transport of particulates and soluble forms of CoC occur along the soil surface when the influx rate of water exceeds the rate of percolation into the soil profile. Water percolating into the soil profile carries soluble forms of CoC into the vadose zone. This soil water may be transported downward until it contacts groundwater, which then flows through the substructure. These CoC in groundwater may be extracted through wells, flow to surface discharges (springs, streams), or remain in the groundwater.

The presence of air-fall impacted soils and the infiltration of natural recharge and impacted irrigation water provide a means for vertical transport of hazardous substances into and through the vadose zone. Lysimeter results show soil water is impacted in all geomorphic areas of depths of over 75 cm (30 inches). This supports the release of hazardous substances from the soils and continued transport to the underlying water table. The soil water gradients during the summer study period show a general drying at the surface; however, deeper zones maintain a relatively steady matrix potential. Earliest spring 2001 data show low soil matrix potentials at 6-inches, suggesting the potential for downward movement during the spring. Irrigated field areas also show downward gradients immediately after irrigation. Highest concentrations of hazardous substances are found in the soil and lower concentrations usually occur in the underlying groundwater. The presence of a decreasing geochemical gradient also supports the soil to groundwater pathway.

2.2.3 Extent of Pathway Contamination

Aerial deposition of CoC in relation to the Washoe Smelter (Anaconda) diminished exponentially with distance from the stack (Munshower, 1972). Concentrations of Cd in soil, herbaceous vegetation, and grasshoppers were above baseline at least as far as Deer Lodge. Reference concentrations of Cd in herbaceous vegetation and grasshoppers (some 160 km; 100 mi from the smelter) were approximately one-fourth the measured concentrations near the GRKO.

Past sampling related to aerial deposition of CoC has been limited to areas proximate to the town of Anaconda, Montana. Consequently, studies in the 2000 and 2001 field seasons included upland soil sampling to depth, to establish site-specific background concentrations. These analyses confirmed

[6] Report signed 21 December 1976 by Morris W. Bowman, Chief Environmental Engineer, The Anaconda Company, Montana Mining Division. “Main stack emanations October 1976: Anaconda, MT.”

the presence of elevated CoC concentrations in upland, non-irrigated soils throughout the north-south uplands range of GRKO (Moore, 2002). Additionally, the irrigation waters currently applied to the east and west fields of GRKO exceed twice the baseline concentrations for both As and Cu, indicating that CoC continue to be released through the historic irrigation system at GRKO.

2.3 PHYSIOLOGY AND TOXICOLOGY OF METALS AND METALLOIDS

The five elements of concern in this case, As, Cd, Cu, Pb, and Zn, are naturally occurring trace elements. Copper and Zn are micronutrients required for plant, microbe, and animal growth and vigor. Arsenic, Cd, and Pb have no known physiological requirement. Because of the ubiquitous nature of these substances and their prominence in agriculture, a large body of literature has developed during the past century. Phytotoxicity endpoints reported in the literature include seed germination, root elongation, shoot mass and height, root mass and length, chlorosis, and seed production (yield). Microbial processes and soil invertebrate responses to these substances have also been studied extensively.

2.3.1 Essential vs. Non-essential Nutrients

Copper and Zn are required by living organisms for normal growth and survival. Copper is a constituent of a number of plant enzymes and activates certain enzyme systems, often influencing the photoreaction center within leaves and electron transport pathways in respiration in all cells. Similarly, in microbes and soil invertebrates, copper is also required for many enzyme functions. Copper is critical for proper functioning of electron transfer processes in respiratory cytochrome systems found in all living cells. Zinc is an important essential mineral for animal, microbe, and plant species. Zinc is a structural metal in many enzymes and is essential for enzyme activity. Zinc also contributes to the configuration of DNA and RNA. Plants and microbes must be exposed to levels of these elements in soil or water, and animals must have these elements in their diets in sufficient quantity to meet physiological needs. The exact required concentration varies with age, developmental stage, species, and in some cases in proportion to other essential elements. Organisms have evolved regulatory mechanisms that enable them to concentrate substances to levels above that in the environment at low environmental concentrations, or exclude substances at high environmental concentrations. For the essential elements, low bioavailable concentrations result in nutritional deficiencies. Homeostatic processes enable organisms to maintain fairly constant tissue concentrations across intermediate environmental concentrations, referred to as sufficiency levels. Excess levels of substances, that is above sufficiency levels, trigger toxicity. Arsenic, Cd, and Pb are not required for any organism.

2.3.2 Mechanisms of Toxicity

Toxicity of metals and metalloids is complicated by many physiological and environmental factors. Relationships of nutritional requirements, tolerance mechanisms, and factors affecting bioavailability influence susceptibility to these substances in soils. Nevertheless, metals and metalloids are known to cause a wide range of adverse effects in plants (Figure 6) and other organisms. These effects range from very specific physiological disorders to broader responses such as reduced growth or death. At the physiological level, metals and metalloids interfere with the plant's energy systems, enzyme functions, growth processes, and cell division. Death occurs at cellular, tissue, organ (e.g., leaves, stems, roots), and whole plant levels.

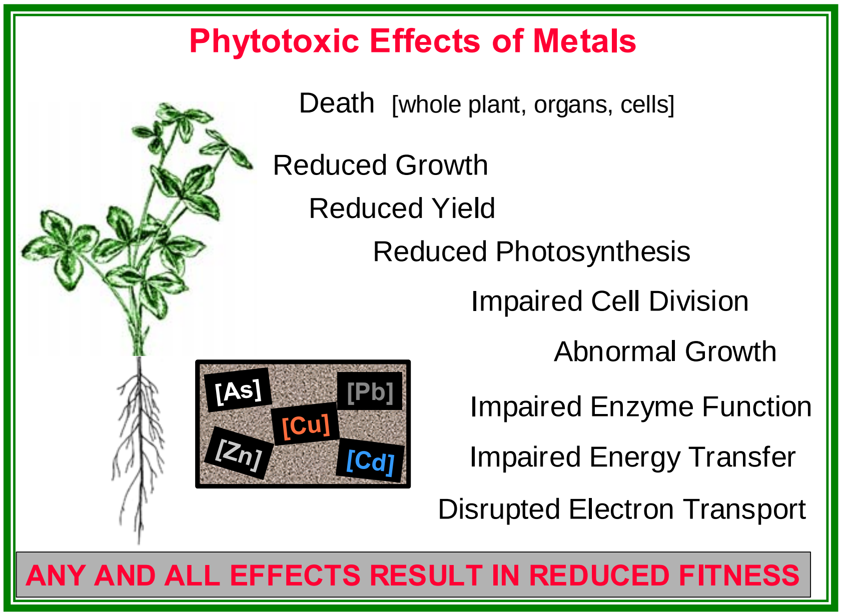

Figure 6. Phytotoxic effects of Constituents of Concern.

Toxicity occurs when an organism is overwhelmed by a chemical substance. In physiological terms, toxicity occurs when an organism loses the ability to maintain homeostasis, resulting in a loss of functions required for normal growth or to sustain life. Generally, this occurs at one or more internal cellular locations or may affect an entire organ. For plants, toxicity may also occur at the root surface without the substance ever entering the internal portions of the plant. Similarly, with microbes, toxic effects may occur at the external membrane surface. Extracellular enzyme function may also be diminished by metals and metalloids.

The site of toxic action may be an enzyme, a membrane, or a co-factor critical to some biochemical pathway. Often, there may be multiple sites of action for a particular substance and toxicity may be manifest in different ways, depending on how the primary modes of action and the cascade of secondary effects are linked. For many toxicity endpoints, such as reduced growth, reduced yield, or death, there are likely to be multiple disruptions of biochemical functions. For example, a phytotoxic response of reduced growth might be a result of impaired photosynthetic function, impaired respiration, and impaired water uptake by roots. Any one of these impairments would be detrimental over a longer time, but when all occur simultaneously, the response time is lessened.

2.3.2.1 Arsenic

Arsenic is a metalloid and, as such, displays chemical characteristics and behavior distinct from elements of the metal series (e.g., Cd, Cu, Zn and Pb). The availability of As to plants and the potential for plant toxicity depends on many factors, including soil pH, texture, fertility level, and plant species. In general, As is most available to plants in coarse-textured soils having little colloidal material and ion exchange capacity, and is least available in fine-textured soils high in clay, organic material, iron, calcium, and phosphate (NRCC, 1978). At comparatively low concentrations, As stimulates growth and development in various species of plants and animals. Such effects, referred to as *hormesis*, seem to be caused by over-compensation of regulatory hormones that modulate homeostasis. This results in non-linear responses to exposure.

Plants and other organisms tend to have a relatively poor capacity to discriminate arsenate from phosphate. Because phosphate is central to so many critical metabolic processes, As toxicity may be manifest with many endpoints. Inorganic arsenate of low solubility makes up the largest fraction of soil arsenic. Arsenate is taken up by the phosphate carrier mechanism. Arsenic may link to sulfhydryl residues of protein, making the protein less than fully functional, thereby exhibiting toxic effects. Arsenic also inhibits fatty acid synthesis and degradation. It may also cause chlorosis (yellowing or bleaching of green plants). Phytotoxicity of arsenic in soils is reduced with increasing alkalinity, organic matter, iron, zinc, and phosphate levels (NRCC, 1978). Although As may be readily soluble and easily leached from soils, As toxicity can persist in soil for several years (Woolson, 1975). An early indication of plant injury by sodium arsenite is wilting caused by rapid loss of turgor (the normal distension in a live cell), whereas stress caused by sodium arsenate does not involve rapid loss of turgor (NAS, 1977). Arsenite acts primarily by inhibiting light activation, probably through interference with the pentose phosphate pathway (Marques and Anderson, 1986). Phytotoxicity of organoarsenical herbicides is characterized by chlorosis, cessation of growth, gradual browning, dehydration, and death (NAS, 1977). Although As is not an essential plant nutrient, small yield increases have been observed at low soil As levels, especially for more tolerant crops such as potatoes, corn, rye, and wheat (Woolson, 1975), consistent with the phenomenon of hormesis. However, for most crop plants, significant depressions in yields are evident at 25 to 85 ppm of total soil As (NRCC, 1978). A soil concentration as low as 2 ppm soluble As is considered the threshold level for marked damage to alfalfa and barley, whereas 3.4 to 9.5 ppm soluble As causes “poor condition” of young seedlings (Chapman, 1966). Phytotoxicity in Bermuda grass ranged from 45 to 90 ppm in sand and clay soils, respectively. Alfalfa grew poorly in soils containing only 3.4 to 9.5 ppm when soils were acidic, lightly textured, low in phosphorus and aluminum, high in iron and calcium, or with excess moisture (Woolson, 1975).

2.3.2.2 Cadmium

Cadmium (Cd) is not essential to any living organism, and is a known teratogen, carcinogen, and mutagen in animals (Eisler, 1985). Many interactive factors modify the plant uptake process. Cadmium uptake is influenced by the sulfides and sulfites present in the soil. Also, associated with ammonium uptake, the plant releases protons into the soil to balance the electrical charge associated with the uptake of ammonium. This causes the pH in the immediate vicinity of the plant root to drop. In turn, this causes more Cd to be released from soil particles and become available for uptake by the plants. Cadmium usually remains in the upper portion of the soil profile. Calcium, Zn, and H ions can compete with Cd for sorption sites in soil or can significantly desorb Cd from soil. Cadmium availability depends on adsorption/desorption rates, pH, Eh, and chemical speciation. Plant- or fungi-mediated uptake of Cd occurs as the divalent cation (Cd^{+2}). Cadmium is taken up by roots and translocated sparingly in various forms of organic and inorganic molecules throughout most plant tissues.

Cadmium interferes with calcium, a substance that is pivotal to many regulatory processes in cells. Cadmium reduces photosynthesis, growth, and yield. Additive phytotoxic effects occur with zinc and cadmium. Cadmium and Zn are closely associated in geologic deposits and have a similar chemical behavior. The Cd to Zn ratio in soils is thought to be biologically important, as Zn may lessen the toxic effects of Cd, and Cd may displace Zn, creating a potential deficiency. Cadmium phytotoxicity has been reported using a variety of endpoints including photosynthesis, growth, yield, and morphological aberrations. Growth inhibition and morphological deformation were apparent in lettuce and soybeans at soil Cd concentrations between 4 to 14 ppm. At these same concentrations, Cd affected tomatoes and cabbage less than it affected lettuce and soybeans. At a higher concentration (i.e., 150 ppm soil), Cd affected photosynthesis, although its mode of action on this process is unknown. Additive phytotoxic effects of Zn and Cd were found using split root tomato plants (Smith and Brennen,1983). The uptake of the two metals was not affected, although other plant physiological processes were altered through the interactive effects of the two metals.

2.3.2.3 Copper

Copper phytotoxicity is expressed in many ways: reduced growth, reduced branching, thickening, and abnormally dark coloration in the rootlets, chlorosis, and reduced yield. Excess Cu inhibits a large number of plant enzymes and interferes with photosynthesis, pigment synthesis, respiration, and membrane integrity. As is the case with Cd or Zn, Cu is a transition metal.

Threshold response concentrations and endpoints affected vary among species tested. Copper generally has greater effect on plant root growth than shoot growth (Baszynski *et al.,* 1982; Gupta and Mukherji, 1977). Root elongation is a more sensitive indicator of Cu effects than root initiation (Hogan and Rauser, 1981). Tomato growth was inhibited at soil Cu concentrations above 150 ppm at pH below 6.5 and above 330 ppm at pH above 6.5 (Rhoads *et al.,* 1989). Black bindweed (*Polygonum convolvulus* L.) had reduced survival at soil Cu concentrations of 125 ppm and reduced seed production at 200 ppm (Kjær and Elmegaard, 1996). Chhibba *et al.* (1994) found that wheat yield significantly decreased with soil Cu concentrations greater than 40 ppm with a calculated threshold concentration of 8 ppm Cu. Oats (*Avena sativa*) exposed to 400, 600, and 800 ppm Cu on cultivated soils and 150 and 300 ppm Cu on uncultivated soils had reduced grain and straw yields for both soils at the lowest concentration tested one and four years after application (Tikhomirov *et al.,* 1988). Plants were more sensitive to Cu additions in uncultivated soil. Oat yields were significantly reduced with 100 ppm Cu and higher in soil (Rhoads *et al.,* 1992), but at a Cu concentration of 400 ppm, yields were improved by the addition of lime and phosphorus. Mosses and lichens vary greatly in their sensitivity to Cu, with threshold concentrations (for survival) of Cu in soil ranging between 80 and 1000 ppm (Folkeson and Andersson-Bringmark, 1988).

Plant species vary greatly in their genetic potential for tolerating elevated Cu concentrations. Cu tolerance can evolve rapidly in populations of many short-lived plant species through the natural selection of those few tolerant individual plants present in normal populations on uncontaminated soils (Wu and Bradshaw 1972, Turner 1994). Trees and other long-lived species show little evidence of Cu tolerance. Although mature trees may survive at Cu contaminated sites, regeneration through seedlings (the most sensitive life stage) appears to be inhibited. The result is that sites heavily contaminated with Cu alone, or Cu with other metals, often support a sparse flora with low species richness (Ernst, 1990).

Copper is toxic to many species of fungi. Fungal species diversity decreased with increasing Cu concentration during a five-month laboratory study; 31, 31, 30, 27, 25, and 19 fungal species were isolated from soils containing 0, 100, 200, 400, 800, and 1600 ppm Cu, respectively (Yamamoto *et al.,* 1985). Decreases in soil fungal diversity related to heavy metals have been reported in other studies (Lawrey, 1977; Zibilske and Wagner, 1982). In soils containing populations of fungi, bacteria, and actinomycetes, Cu had the greatest impact on fungi (Wang *et al., 19*86).

Copper and other heavy metals generally are known to inhibit decomposition of soil organic matter, soil respiration, nitrogen mineralization, and nitrification in a manner dependent upon the form of the chemical, the amount of organic matter in the soil, and the soil pH (Hattori, 1992). In response to Cu, microbial species diversity is lowered and microbial functions are impaired. Microbial biomass carbon and phosphorus, substrate-induced respiration, and denitrification decreased significantly with increasing metal contamination in the soil in a pasture contaminated with a timber preservative containing Cu, Cr, and As (Bardgett *et al*., 1994). Metal stress caused a decrease the degradative capabilities of soil bacterial communities in metal contaminated and uncontaminated soil from Canada and Germany (Burkhardt *et al*., 1993).

Biological nitrogen fixation by heterotrophic nitrogen-fixing bacteria was reduced significantly at soil pH >6 and 50 ppm Cu in soil (Mårtensson, 1993). At 125 ppm soil Cu, nitrogen fixation by surface-dwelling cyanobacteria was significantly reduced. Heterotrophic biological nitrogen fixation was significantly reduced at soil Cu concentrations of 75 ppm, independent of soil pH or carbon and nitrogen content of soils (Mårtensson, 1993) even though nodulation is not affected at such low concentrations. Nodulation of clover was detected in soils up to 370 ppm Cu (Smith, 1997).

The effects of Cu on plant communities are a function of direct toxicity to individual plant survival and reproduction, alterations of soil-mycorrhizal-plant interfaces, and disruption of plant decomposition processes that release nutrients to the soil. Several studies document the reduction in plant community diversity and productivity resulting from exposure to Cu and other heavy metals. For example, the plant community at the refinery site in Merceyside, northwest England with mean soil Cu concentrations of 11,000 ppm was low in diversity and dominated by metal-tolerant species, such as *Agrostis stolonifera* and *Festuca rubra* (redtop bentgrass and red fescue; Hunter *et al*., 1987). In these species, the binding of Cu to root cell walls reduced the effects of increases in the soil Cu concentrations. Although the water-soluble Cu concentration was 55 times greater at the refinery than at the control site, there was only a four-fold increase in the leaf and shoot concentration in *A. stolonifera.* Copper concentrations in plants at the refinery site also varied with the season. The highest concentrations in *A. stolonifera* occurred during winter months due to translocation of Cu into older shoots and leaves prior to senescence and due to surface deposition of particulates. Copper concentrations in plants were diluted by new growth in the spring.

Litter decomposition rates were nearly seven-fold higher at a control site compared to a site 1 km from a Zn smelter in Pennsylvania (Cu concentration of 340 ppm in soil), indicating that not only the structure, but also the biological functioning of the soil community was disrupted (Strojan, 1978). A significant reduction in leaf litter decomposition rate near the smelter could lead to an increase in the standing mass of un-decayed litter, eventually affecting primary productivity by limiting the cycling of essential plant nutrients (Tyler, 1972). Aerially deposited metals concentrate in the upper organic horizons by ion exchange, surface adsorption, and chelation-reaction mechanisms and persist for long periods of time, hindering recovery of the soil community.

Grassland species composition changed with the accumulation of 280 to 327 ppm Cu in the top 5 cm of soil from a facility emitting Cu primarily aerially as Cu oxides, (Lepp *et al*., 1997). The area was sown with known grass mixtures in 1975, and plant community composition was determined approximately 20 years later. The species compositional structure and aerial coverage changed significantly from the composition of the original seed mixture. Perennial ryegrass (*Lolium perenne*) was absent from most current plant communities, even though seed mixtures contained 20% to 25% ryegrass. *Agrostis capillaris* showed the greatest tolerance of Cu and was the dominant grass at all sites (*A. capillarus* from uncontaminated sites did not possess the same degree of Cu tolerance, Dueck *et al*., 1987). Broad-leaved herbs were found to be very sensitive to a combination of elevated levels of Cu.

Elevated Cu concentrations also may affect plants indirectly through effects to fungi. Endophytic fungi enhance resistance of their host plants to insect herbivores, but some species are very sensitive to Cu and other heavy metals. Conversely, metals may affect endophytic fungi indirectly by altering environmental factors such as stand density, site humidity, and tree height (Ranta *et al*., 1994). The mycorrhizal association between higher plants and ectomycorrhizal fungi can modify the toxicity of heavy metals for higher plants. However, highly contaminated sites are directly toxic to mycorrhizal fungi, limiting colonization to a small set of non-mycorrhizal, Cu-tolerant species (Griffioen *et al*., 1994).

2.3.2.4 Lead

Lead, a member of the metal group on the periodic table, is tightly held in the soil and is taken up sparingly by plants at low pH, low phosphate, and low soil organic matter. Soils with higher organic content and similar pH will hold Pb and other heavy metals more strongly so that a smaller percentage of Pb is made available to plants. Interactions between Pb, other elements, and environmental factors complicate the process of establishing toxic soil Pb concentrations.

Toxicosis from Pb in plants is expressed by reduction in growth, photosynthesis, mitosis, and water absorption. Roots in contact with Pb degenerate as cell division in root meristems decreases (Wierzbicka, 1989). The activity of many enzymes is inhibited as Pb blocks sulfhydryl groups in proteins (Eisler, 1988). Lead in roots probably competes with calcium, which plays a role in cell division of actively growing roots. Thus, lead causes generalized disruption of cell division, impairing root growth and function. Lead does not affect mature leaf tissues as readily as growing leaf tissues, where inhibition of chlorophyll and carotenoid synthesis may be an indirect effect of root inhibition. Lead inhibits plant respiration and photosynthesis through disturbance of electron transfer reactions and $C0_2$ formation in chloroplasts (Miles *et al.*, 1972). Phytotoxic Pb levels in soil range from 100 ppm to 2,000 ppm. Sensitive crops may be considerably damaged in soils with higher available Pb content (i.e., lower pH) at levels lower than 1,000 ppm. At 1,000 ppm total soil Pb level, significant yield reductions may occur in alfalfa, barley, oats, and lettuce in soils with pH values less than 6.0.

2.3.2.5 Zinc

Zinc is an important essential mineral for most animal and plant species. Zinc is a structural metal in many enzymes and is essential for enzyme activity (Riordan and Vallee, 1976). Zinc also contributes to the configuration of DNA and RNA (Kabata-Pendias and Pendias, 1992).

Plant and fungal-mediated uptake of Zn is influenced by soil pH, soil composition, organic matter, and phosphorus levels. Zinc availability to plants is enhanced in acidic soils, as with many metals. High levels of soil calcium and phosphorus reduce Zn availability to plants, lowering the risk of plant toxicity (Kabata-Pendias and Pendias, 1992). Plant uptake of Zn is also influenced by the organic matter content of soil, chelating compounds, and soil fertility (Kabata-Pendias and Pendias, 1992).

Symptoms of Zn toxicity include stunted growth, reduced yields, reduced leaf size, necrosis of leaf tips and shoot apices, a reddish tint near the basal part of leaves, and curled, distorted foliage. Total soil Zn concentrations in excess of 600 ppm in soil were associated with yield reductions greater than 25 percent in many crop species. Typical phytotoxic criteria for total soil Zn range from 250 to 500 ppm (Kitagishi and Yamane, 1981; Chapman, 1966). Yield reductions in most species are low at concentrations less than 200 ppm, while levels greater than 200 ppm result in increasing yield reductions for many crops. Vegetative yields for barley and wheat were reported to decrease by 16% and 18% at total soil Zn concentrations of 200 ppm and 300 ppm respectively (Boawn and Rasmussen, 1971). Mitchell *et al*. (1978) noted reductions in wheat grain yields of 3 to 14% in the 100 to 180 ppm total soil Zn range and 12 to 29 percent at 340 ppm total soil Zn (CH2M Hill, 1986). A wide range of Zn phytotoxic levels has been reported for plants. Phytotoxic Zn levels range from 60 ppm for wheat plants (Takar and Mann, 1978) to more than 800 ppm for swiss chard (Boawn, 1971). Most values for cereal grains and forages fall between 189 ppm and 560 ppm, with 35 and 20 percent yield reductions, respectively (Mitchell *et al*., 1978; Boawn and Rasmussen, 1971). Boawn and Rasmussen (1971) reported 20 percent yield reductions for barley, wheat, and alfalfa at plant tissue levels of 540 ppm, 560 ppm, and 295 ppm, respectively. Zinc phytotoxicity to barley seedlings was reported in the range of 160 ppm to 320 ppm (Davis *et al*., 1978).

2.3.3 Toxicity Threshold Values

Toxicity thresholds refer to concentrations above which organisms exhibit adverse effects such as reduced growth or increased mortality. Data from a single experiment or from several studies (either laboratory or field observations) are used to identify thresholds (Figure 7). Literature reviews of toxicity studies are often aimed at identifying the lowest concentration of a substance at which adverse effects were reported. These values are useful in attempting to find an environmental concentration protective of all species. However, many soil factors alter the concentration response relationships. Most commonly, pH, organic matter content, soil texture, and relative amounts of other substances (e.g., calcium, iron, etc.) influence bioavailability and therefore the threshold concentration for a particular field situation. Also, the chemical form of the substance can be very significant. Because of this, some literature reviews have emphasized ranges of toxicity threshold concentrations. Comparisons of data reporting the most sensitive species response to those that are most resistant help to define expectations under field situations. As environmental concentrations approach the higher threshold values, it becomes more likely that many more species would be harmed (Figure 7). At environmental concentrations substantially above the higher threshold values, serious and sustained injury to most or even all species can be expected (Figure 8). Ranges of soil concentrations (ppm or mg/kg) as general indications of phytotoxicity may be compiled from several independent reviews and studies (Table 3).

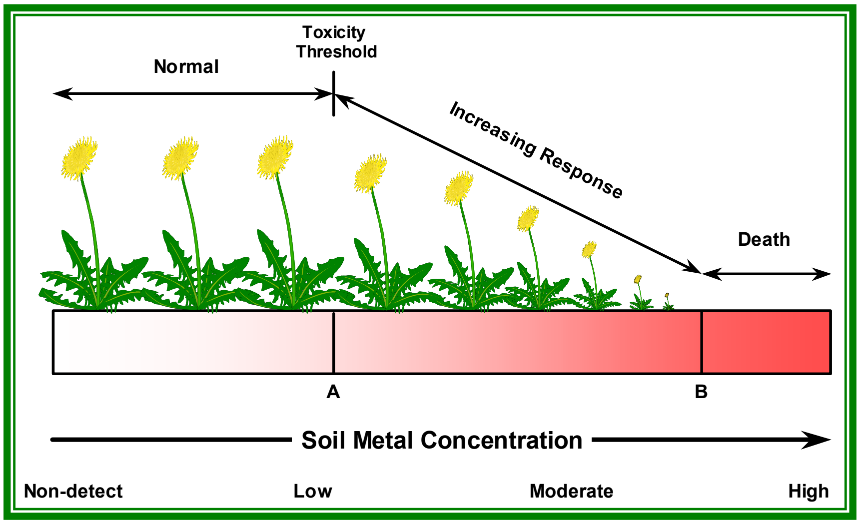

Figure 7. Relationship of CoC concentration and phytotoxic response.

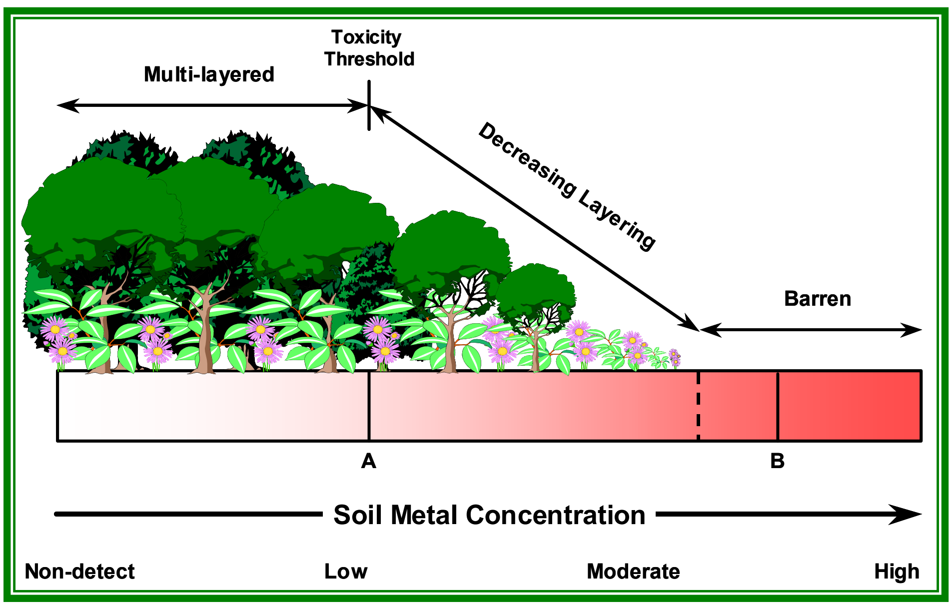

Figure 8. Relationship of metal concentration and vegetation response.

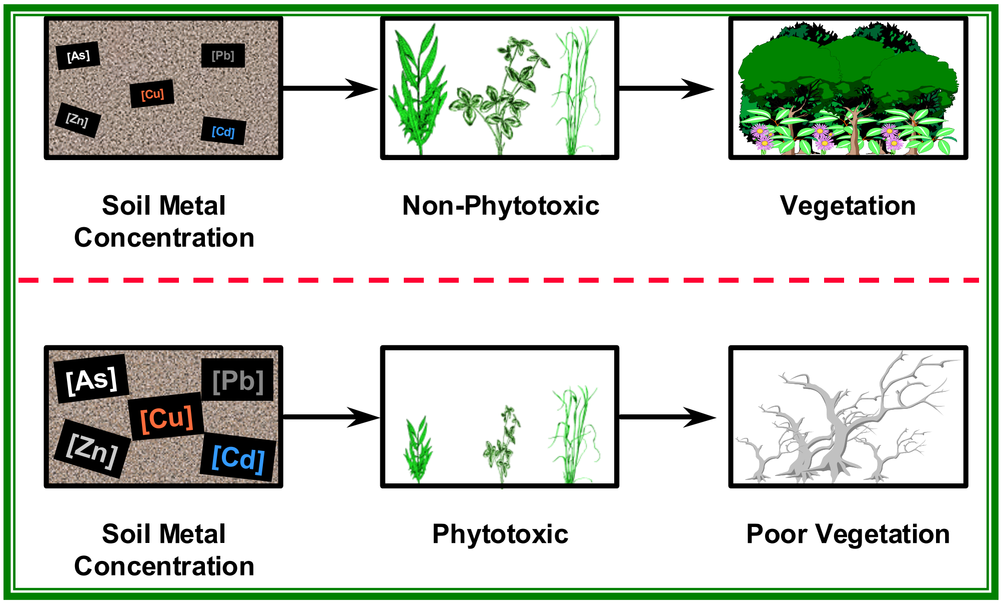

Figure 9. Relationship of phytotoxicity and vegetation response.

The type and degree of response depends on the concentration of the metal or metalloid to which the plant is exposed. For each metal or metalloid, a plant will have a toxicity threshold concentration. That is, at lesser concentrations normal physiological activities will occur. The degree of response increases with increasing concentration of the substance. At some concentration, the poisoning effect is such that death of the plant occurs (Figure 9).

Table 3. Phytotoxicity Threshold Values.

element	low threshold[1]	upper threshold[2]	Draft EPA Eco-SSLs[3]
As	10	100	36
Cd	3	100	20
Cu	60	150 (250)	95
Pb	100	1,000 (10,000)[4]	148
Zn	70	400	132

[1] Lowest reported value from various sources (including Alloway, 1995; **ep** and **t**,1995; Kabata-Pendias and Pendias, 1992).

[2] Highest reported value from various sources (including Alloway, 1995; **ep** and **t**,1995; Kabata-Pendias and Pendias, 1992).

[3] Draft concentrations from US EPA Ecological Soil Screening Levels to be published in 2002. Values are intended to be a safe level for soils with maximum bioavailability.

[4] **ep** and **t**,1997.

Similar ranges exist for soil microbes and soil invertebrates, though microbes tend to have lower low thresholds and slightly higher tolerance levels than other groups. Metals and metalloids interfere with membrane function, biochemical pathways, electron transport processes of soil microorganisms and soil invertebrates (Figure 10).

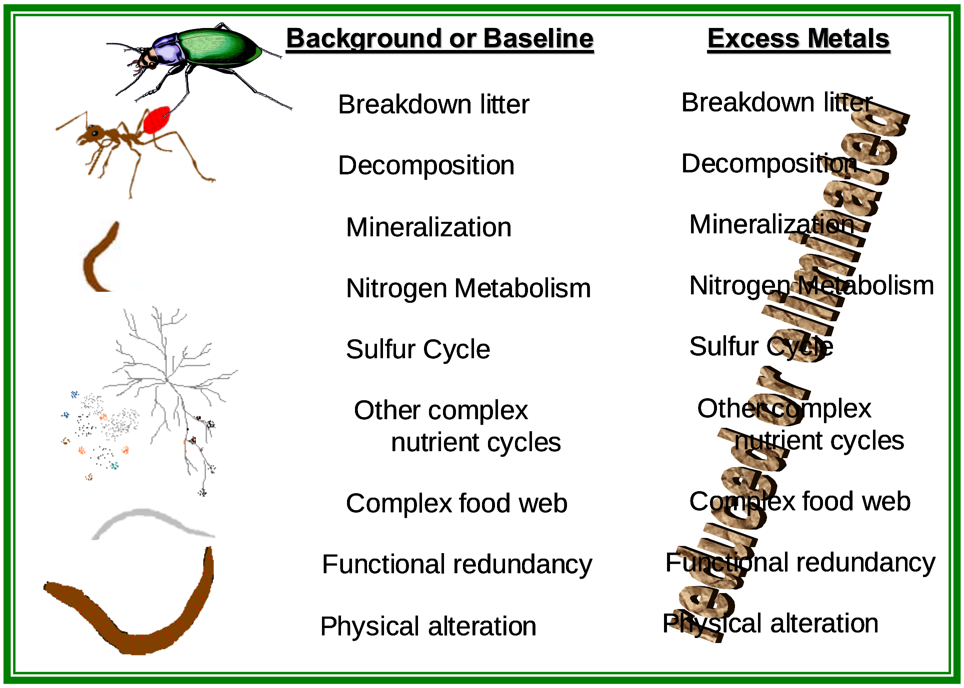

Figure 10. Relationship of CoC concentration toxicity to microorganisms and soil invertebrates.

2.4 Ecological Consequences of Toxicity

Toxicity test methods are designed to measure the response of individuals to test substances or mixtures of test substances. Except for rare or endangered species, public policy and law are focused on population effects or higher levels of ecological organization (e.g. community or system's functions).

At soil metal concentrations above the deficiency zone but below the phytotoxic threshold concentrations, the soil is not toxic and, therefore, normal, complex communities will develop. At concentrations above the threshold, the soils are phytotoxic. This results in poor or no vegetation. In a plant community, there are many individuals of many species. Typically, there are several canopy layers formed by the different species. For example, an upper canopy of mature trees, one or more sub-canopy layers formed by smaller trees or shrubs, herbaceous layers, and ground layers. As toxicity effects occur in different species, the complexity of the community decreases. Where conditions become toxic to most species, the landscape becomes barren. Because field conditions include many other stresses such as drought, temperature extremes, disease, and insect infestations, the landscape can become barren at concentrations less than might be required to kill plants in short-term laboratory tests.

Bacteria and fungi are part of every ecological system. In the terrestrial environment, decomposition of organic material governs the rate of mineralization (release of essential nutrients from organic form to inorganic ions). This, along with microbial processes that alter the oxidation state of various anions and cations, is an important determinant of soil fertility. Direct interactions with plant roots in the form of associative bacteria and symbiotic bacteria and mycorrhizal fungi have been shown to have critical roles in governing diversity and productivity of plant communities. Mycorrhizal fungi are important for development of dynamic plant communities. Estimates are that more than 95% of all plant species and 99% of all plant individuals are mycorrhizal dependent – that is to say that elimination of mycorrhizal associations leads to dramatic shifts in the composition of the plant community. Similarly, associative and symbiotic soil bacteria are critical to the normal functioning in the rhizosphere, a zone around the roots of plants.

Soil invertebrates have substantial influence on development and maintenance of fertile soils. Various nematodes, earthworms, centipedes, springtails, enchitrids, isopods, spiders, and insects live in soils. Interactions of microorganisms and soil invertebrates result in the breakdown of plant roots and litter. Soil invertebrates not only accelerate decomposition of plant litter, they also influence soil structure and aeration as they burrow, ingest, digest, transform, and defecate in the upper horizons of soil. These conversions provide turnover of nutrients in soil that are critical to soil fertility.

Toxicity to microorganisms and soil invertebrates can have severe consequences affecting ecological systems (Figure 11). The biomass of microorganisms and soil invertebrates exceeds the mass of vertebrates. At modest concentrations of hazardous substances, species changes occur among the microorganisms and to some extent soil invertebrate communities. Often, such changes do not markedly alter ecological functions. However, with sustained exposure to high concentrations of hazardous substances, ecological services provided by microorganisms and soil invertebrates are diminished. The consequences of such sustained injuries are extended to the plant community.

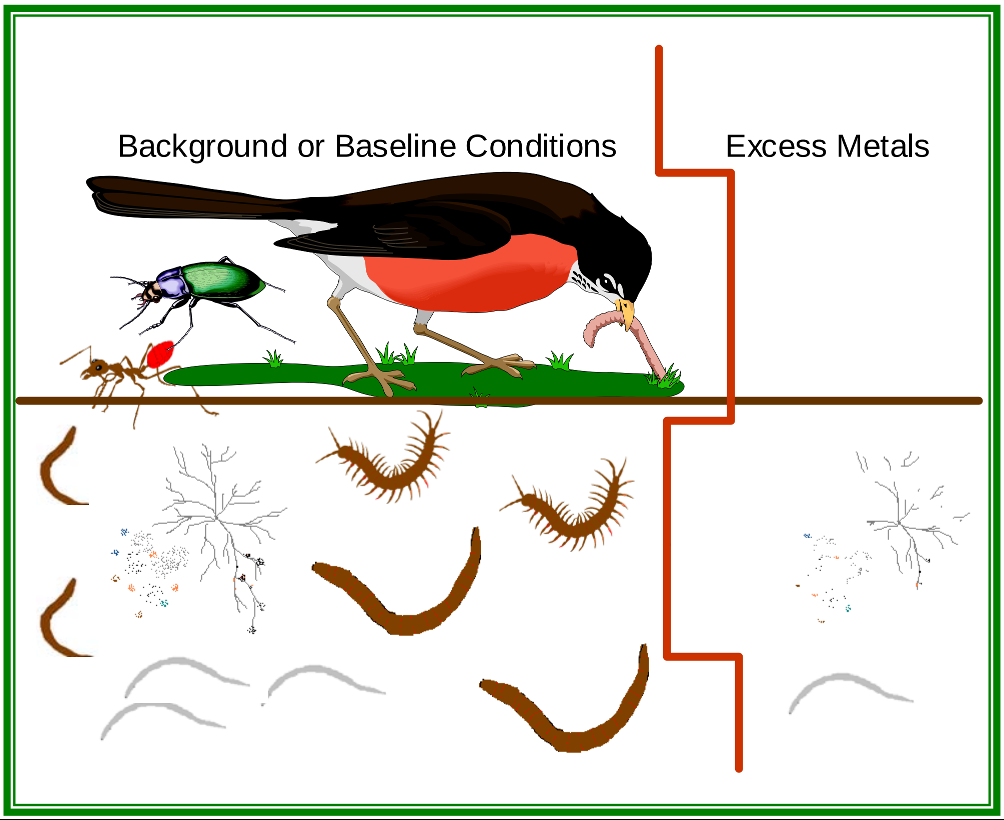

Figure 11. Consequence of toxicity to microorganisms and soil invertebrates.

The CoC at DOI tracts have known toxic effects on many soil microorganisms, plants, soil invertebrates, and other biotic groups. Prior studies by Rader and Nimmo (See Appendix A. Annotation of Prior Studies) have shown inhibitory effects on soil invertebrates.

3 GEOLOGIC RESOURCES -- RIPARIAN AND UPLAND SOILS: GRKO

Generally, riparian soils support the most productive vegetation types within a region and therefore are among the most critical features of landscapes. In turn, the lush vegetation provides food and shelter for wildlife or domestic livestock. Riparian areas were, and remain, the most prized lands for ranching and farming due to the ready access to water for livestock and irrigation of pastures and fields. As an active cattle ranch and as part of its historical context, a significant portion of the GRKO is comprised of riparian lands.

3.1 DESCRIPTION OF THE RESOURCE

Detailed technical descriptions of vegetation cover of the GRKO in the 1860s have not been found. Therefore, baseline vegetation conditions of the area must be inferred from general knowledge of plant community characteristics. Because ecological systems are dynamic, precise quantities of each community type cannot be determined due in large part to the substantial physical changes that occurred during flood events (especially the 1908 flood). Nevertheless, ecological principles and processes indicate that a dynamic mosaic[7] of vegetation types occupied these lands prior to the considerable disturbances caused by mining in the upstream areas.

Extensive characterization of plant communities in Montana was developed during the latter half of the 20th century. For riparian areas and wetlands of Montana, this is embodied in the publication by Hansen *et al.* (1995). They recorded not only the compositional characteristics of recognizable plant communities, but conveyed their extensive knowledge of successional patterns to classify certain communities that persist because of continued disturbances (e.g., grazing) and others that have remained relatively unchanged over time (See Text Box on page 26). The types of vegetation that existed on the DOI lands in the 1860s were portrayed from this descriptive information.

The system developed by Hansen *et al.* (1995) for classifying riparian vegetation in Montana was used as the basis for setting baseline conditions and restoration goals. A four-stepped process was used:

1. The plant communities currently occupying the GRKO floodplain were determined and mapped in the summer of 2000.

2. The successional pathways were considered to identify any additional communities that are presently absent from the riparian zone.

3. Grazing “disclimax” (disturbance) communities were excluded from the list of baseline community types.

4. Non-indigenous and infrequently occurring native species were removed from the species lists for each community type.

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[7] *Dynamic mosaic* has been used to describe patterns of vegetation on regional landscapes, in which the relative percentages of early successional through late successional community types remains fairly constant, even though local changes are evident. For example in a riparian zone, natural bank erosion exposes new surfaces that become colonized with early successional species at approximately the rate of transition of previously established areas, which progress into later successional community types.

Ecological Concepts and Terminology

The terminology used in Hansen *et al*. (1995) is derived from the Daubenmire school of ecology, referred to as the Poly-climax Theory (Daubenmire, 1968). *Climax communities* are those, which barring external disturbance such as grazing, fire, harvest, flooding, etc., would persist relatively unchanged. *Disclimax communities* are those, which develop in response to a disturbance; and, so long as the disturbance regime remains constant, will persist relatively unchanged in this altered state. A central premise of the Poly-climax school is that communities exist as discrete, recognizable entities.

Alternative views on community dynamics are more prominently held among contemporary ecologists. In particular, the Continuum Theory (Curtis and McIntosh, 1951; Curtis, 1955) holds that species (indeed Individuals) are distributed along environmental gradients (e.g., moisture, temperature, light intensity, etc.). Sharp gradients (e.g., change in soil type over a short distance) are reflected in sharp changes in vegetation; conversely, gradual gradients are reflected in gradual transitions in vegetation.

The underlying philosophies of these alternative schools were debated hotly in the 1960s (Daubenmire, 1966; Cottom and McIntosh, 1966). Significant advances in ecological theory were made in the last three decades on ecosystem modeling and landscape ecology (see Kapustka and Landis, 1998; Turner *et* al., 2001).

A recent conceptual model, *Community Conditioning,* was developed by Landis and his colleagues (Matthews *et al.*, 1996). The community-conditioning concept argues that the history of a system is retained at organismal and ecological levels of organization. Historical influences are difficult, if not impossible, to erase and preclude the existence of equilibria.

Though these could be dismissed as mere academic disagreements, there are important ramifications with respect to characterization of baseline conditions and, ultimately, with modes of restoration. Whereas the descriptions of generalized community types and successional patterns can be accomplished using the classical Poly-climax methods (ala Hansen *et al*., 1995), injury determination and, ultimately, restoration approaches benefit from the mechanistic-based approaches embodied in gradient analyses and ecological dynamics of the continuum approach and community conditioning approach.

Selected References applicable to this text box:

Cottom, G. and R. P. McIntosh. 1966. Vegetational continuum. *Science* 152: 546-547.

Curtis, J. T. 1955. A prairie continuum in Wisconsin. *Ecology* 36: 558-566.

Curtis, J. T. and R. P. McIntosh. 1951. An upland forest continuum in the prairie-forest border region of Wisconsin. *Ecology* 32: 476-496.

Daubenmire, R. 1966. Identification of typal communities. *Science* 151: 291-298.

Daubenmire, R. 1968. Plant Communities. *Harper and Row, New York, NY*

Kapustka, L. A., and W. G. Landis. 1998. Ecology: the science versus the myth. *Human and Ecol. Risk Assessment.* 4: 829-838.

Landis, W. G. and J. F. McLaughlin. 2000. Design criteria and derivation of indicators for ecological position, direction and risk. *Environ. Toxicol. Chem*.19:1059-1065.

Matthews, R. A., W. G. Landis, and G. B. Matthews. 1996. The community conditioning hypothesis and its application to environmental toxicology. *Environ. Toxicol. Chem.* 15: 597 – 603.

Turner, M. G., R. H. Gardner, and R. V. O'Neill. 2001. *Landscape ecology in theory and practice: pattern and process.* Springer-Verlag, New York, NY.

Seventeen plant community types would have existed in the riparian areas of the DOI lands in the 1860s (Table 4, see Figure 12 for contemporary plant communities). Of the seventeen communities, five are classified as seral stage community types (i.e., transitional communities destined to give way to a different suite of species over a relatively short time) and twelve are "climax" habitat types (i.e., those that persist for relatively long periods). The communities included herbaceous wetland types with seasonally high water tables to well-drained types dominated by shrubs and trees. Starting from bare soil it would take three to five years to develop the herbaceous habitat types. The willow habitat types would take fifteen to thirty years to reach maturity.

Historically, localized low-elevation areas (with respect to water table depth) along the waterways exposed from bank erosion and beaver activity, supported water birch, sandbar willow, and cottonwood communities. Snowberry, chokecherry, red-osier dogwood, alder, and woods rose were also prominent. Graminoids (narrow-leaf herbaceous plants including grasses, sedges, and rushes) and forbs (broadleaf herbaceous plants) existed as understory species in the younger woody communities. In older communities, graminoids were dominant or co-dominant with woody species. Nominal baseline community composition of each type consists of from five to 35 native species (compiled list of principal species is presented in Appendix B).

Table 4. Baseline plant community types for the GRKO on the Upper Clark Fork River.

Community Type (number of plant species with greater than 1% cover)	
Transitional (Seral)	"Climax" (Persistent)
Black Cottonwood/Red-osier Dogwood (30)	Beaked Sedge (12)
Chokecherry (22)	Bluejoint Reedgrass (19)
Sandbar Willow (12)	Cattail (5)
Snowberry (16)	Drummond Willow / Beaked Sedge (25)
Water Birch (25)	Geyer Willow / Beaked Sedge (25)
	Geyer Willow / Bluejoint Reedgrass (35)
	Slender Sedge (20)
	Spikesedge (14)
	Tufted Hairgrass (20)
	Water Sedge (11)
	Yellow Willow / Beaked Sedge (30)
	Yellow Willow / Bluejoint Reedgrass (24)

The riparian zone of the GRKO covers approximately 54.4 ha (~135 ac), including the area occupied by the river. When ranching was first established as a predominant enterprise in Montana in the 1880s, the dense vegetation of shrublands and forests intermixed with wet meadows, with strong root masses, stabilized the banks of the stream (Smith *et al.*, 1998). During floods, the vegetation slowed the flow of waters such that suspended materials were deposited across the floodplain, thereby enriching the soils. The dense overstory afforded protection for wildlife and livestock from the sun during the hot summer months and from bitter cold during the long winter periods. Small variations in elevation within the floodplain resulted in slight differences in soil water regimes and associated conditions, such that relative dominance shifted among plant species and contributed to the diversity of plant communities of the region.

In addition to husbandry of domestic animals, ranching activities and the traffic of commerce in general brought about the introduction of many non-native plant species. Some plant species were introduced into pastures to "improve" forage for livestock; others without any intended uses became naturalized accidentally. Many such species (e.g., redtop bentgrass, smooth brome) are permanently integrated into the regional flora.

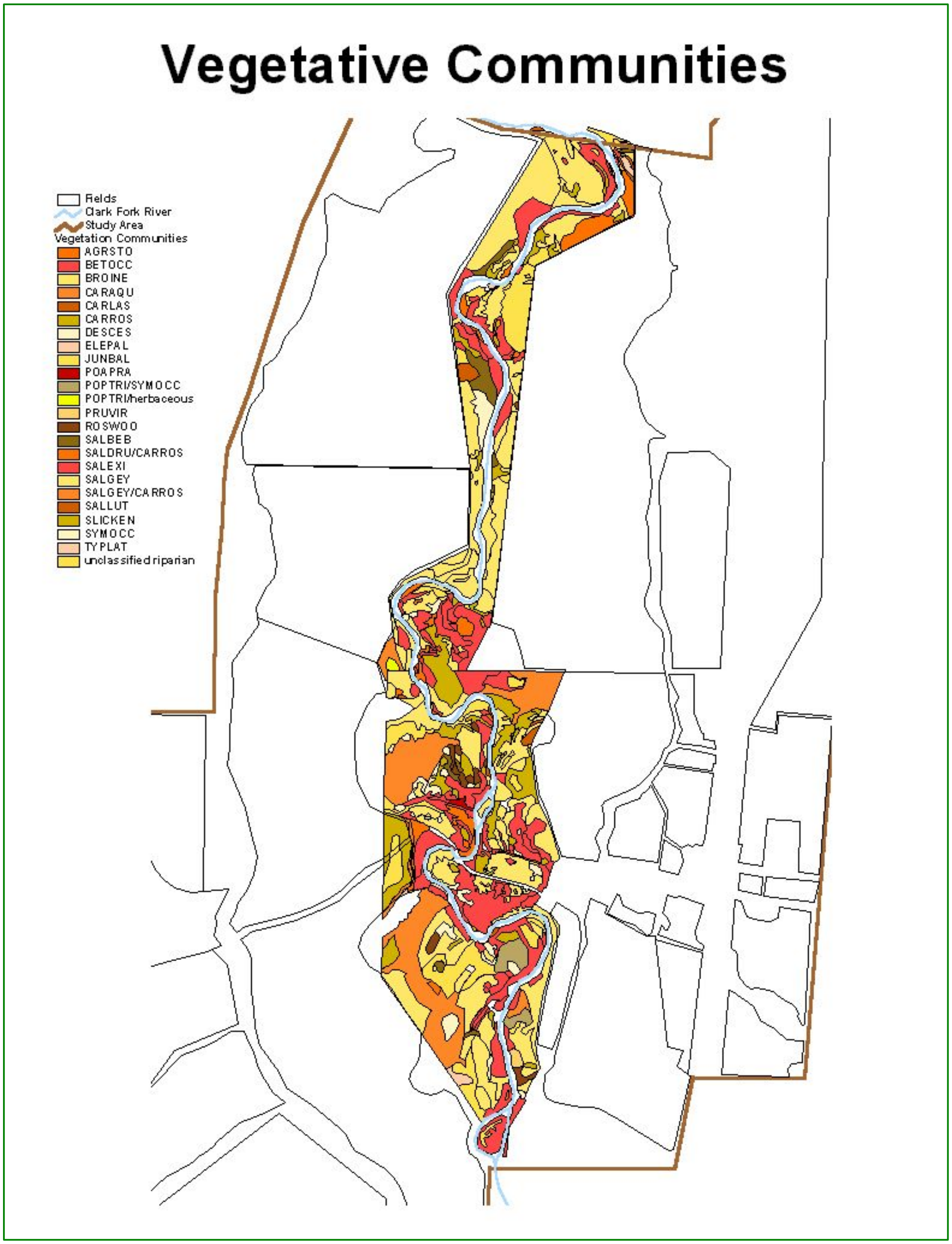

Figure 12. Distribution of current plant communities on the GRKO fenced riparian area.

3.2 INJURY DEFINITIONS

Soil injury is defined in 43 C.F.R. § 11.62 (e). According to this regulation, injury to geological resources has occurred if a release or threatened release of hazardous substances causes, or has the potential to cause, any of the following:

- pH<4.0 or >8.5;
- salt saturation yielding a salt saturation value >2 millimhos per centimeter in soil;
- decreased water holding capacity such that plant, microbial, or invertebrate populations are affected;
- impedance of soil microbial respiration to an extent that plant and microbial growth have been inhibited;
- inhibition of carbon mineralization resulting from a reduction in soil microbial populations;
- toxic response to soil invertebrates; or
- phytotoxic response, such as retardation of plant growth.

A condition satisfying any one of these definitions is sufficient to establish injury to the resource.

3.3 INJURY DETERMINATION AND QUANTIFICATION

Injury was based on historical information and more recent data gathered specifically to quantify injury to soils on the DOI lands. Recent data on riparian and upland soils are presented in four data reports (Gannon, 2002; Kapustka, 2002; and Moore and Woessner, 2001, Moore *et al.*, 2001; Woessner and Johnson, 2002). The quality of data was evaluated and found to be of sufficient quality for their intended uses (Neuman, 2001, 2002). Nearly all of the soil, sediment, and water CoC data were found to meet the highest standards (i.e., enforcement quality as defined in the checklist procedures agreed to by ARCO and USEPA in 2000 for data generated at the Clark Fork River Superfund Sites). Descriptions of the contemporary vegetation and comparisons to baseline conditions were developed from Rice and Hardin (2002) Rice (2002a, 2002b) and Bedunah (2001).

3.3.1 Baseline Metals Conditions

Baseline concentrations of CoC represent the natural levels of these substances prior to mining activities. Previous reports as well as analyses of new data were considered in establishing baseline concentrations for each CoC. The information for this section was derived from the technical report by Moore and Woessner (2001). Data on soil CoC baseline concentrations were obtained from deep soil cores collected on the GRKO in 2000. These data were compared to values reported from previous efforts to determine CoC baseline concentrations.

3.3.1.1 Sampling Design, and Location of Samples, and Analytical Methods

Soil profile sampling was focused on areas along the Clark Fork River floodplain and on the Clark Fork River channel cut banks on GRKO. Two hundred and seventy-three subsurface soil samples to depths of approximately 120 cm were collected from 39 locations (Figure 13). This was comprised of 15 streambank samples, 3 pits, and 21 cores taken with a "Geoprobe."

Chemical analyses were performed using standardized processing and measurement methods. Samples were digested according to a modified EPA Method 3050B for the extraction of total metals. Digests were analyzed for total metals by ICAP-ES as per EPA Method 200.7. Analytes included aluminum (Al), As, calcium (Ca), Cd, chromium (Cr), Cu, iron (Fe), potassium (K), magnesium (Mg), manganese (Mn), sodium (Na), phosphorus (P), Pb, and Zn.

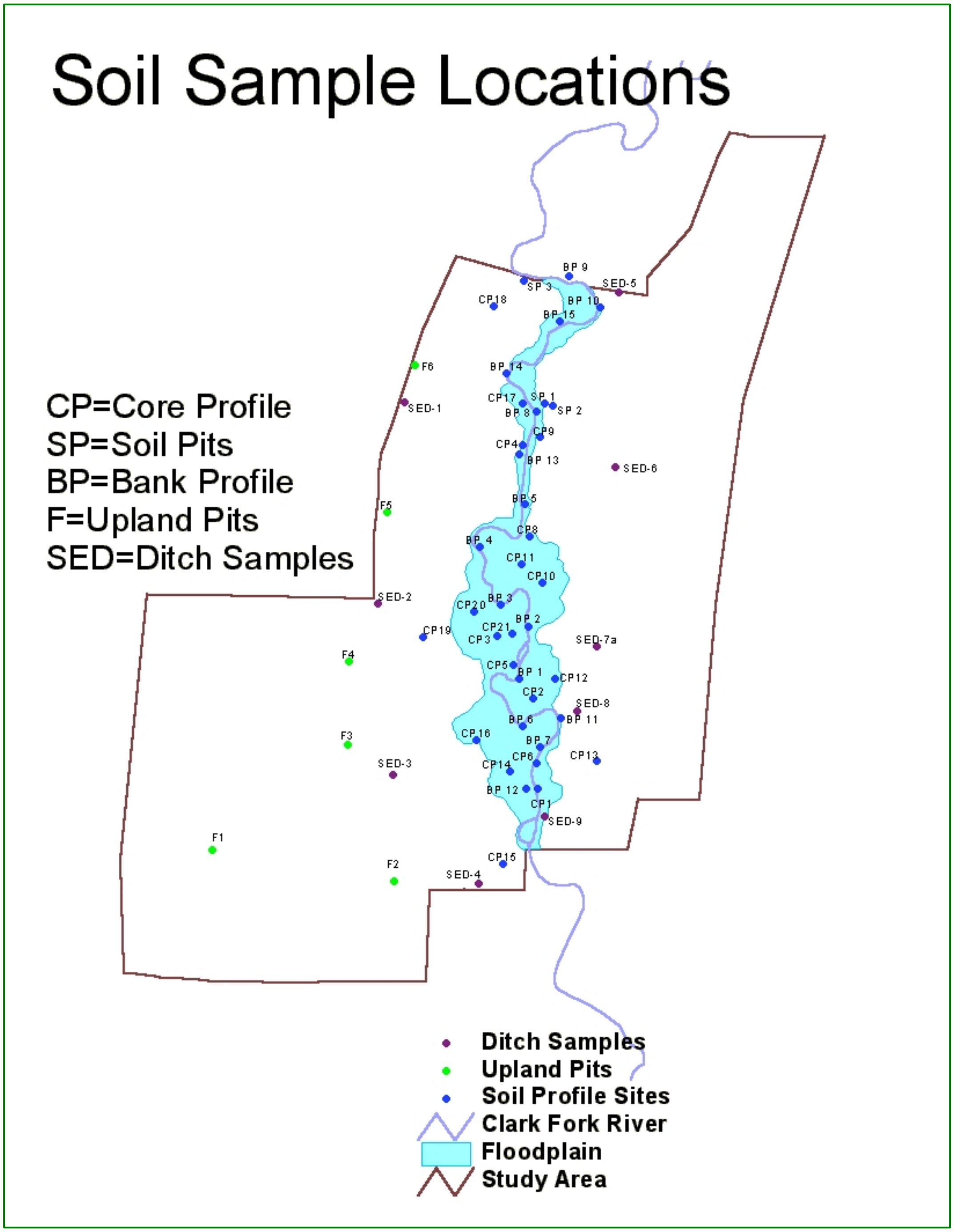

Figure 13. Site map identifying locations of core profile (CP) and bank profile (BP) samples for determination of baseline CoC concentrations.

3.3.1.2 Findings

Plots of CoC concentrations versus depth were prepared for deep soil cores (un-compacted depth of 120 cm) from the riparian zone along the Clark Fork River. Generally, though not always, the highest concentrations were at or near the surface (Compare Figure 14 and Figure 15). At some depth, concentrations dropped to a consistent, low concentration. The consistent low concentration was interpreted to be the pre-mining baseline level of metals and arsenic concentrations. Both fields and floodplain area sites showed consistent low concentrations at depth.

Each CoC in each profile was assessed individually. The depth at which the concentration declined to a constant concentration was determined. This process was repeated for all profiles showing constant values at depth. Data from all profiles containing consistent concentrations at depth were collated and used to calculate baseline concentrations for the GRKO (Table 5). Profiles where concentrations did not have a recognizable and consistent low concentration were omitted from the baseline determination.

Table 5. Determination of baseline concentrations (ppm) inferred as the Median CoC concentrations (ppm) from soil cores from GRKO (Moore and Woessner, 2001).

Element	Baseline [a]	MAD [b]	IQR [c]	Maximum	Minimum	N	% BPQL
As	10	0	2	38	10	118	66%
Cd	1	0	0	1.3	1	94	98%
Cu	16	8.4	20	77	6	98	10%
Pb	17	7	13	170	8	125	15%
Zn	49	22	45	140	14	95	0%

[a] Median values were used to represent baseline. The data were not normally distributed and for As and Cd, many baseline values were below the dilution corrected detection limit, PQL*200.Values used in the median calculation for some elements required corrected PQL values. For additional explanation, see Moore and Woessner (2001).

[b] Median Absolute Deviation

[c] Inter-Quartile Range

These values of CoC baseline concentrations in the riparian zone of GRKO were generally consistent with values reported from other determinations of baseline concentrations in Montana (Table 6). Of the other studies, that of Canonie (1992) on Silver Bow Creek was geographically closest to the GRKO area and has the closest correspondence of values. Because of the large sample size (N ranged from 94 to 125 for the different analytes) and the finer detail employed in the determination of baseline concentrations for the GRKO riparian zone, the data by Moore and Woessner (2001) represent the best determination of baseline.

Table 6. Baseline CoC concentrations (ppm) at GRKO Compared to other studies in Montana.

CoC	GRKO Ranch [a]	Silver Bow Creek [b]	Clark Fork Tributaries [c]	Divide Creek and Little Blackfoot River [d]
As	10	11.1	26.5	27.8
Cd	1	n.d.	<2.5	1.2
Cu	16	26.6	27.0	34.2
Pb	17	19.5	24.0	35.9
Zn	49	98.5	94.0	102.2

[a] Moore and Woessner (2001); [b] Canonie (1992); [c] Moore *et al*. (1989); [d] Lipton *et al*. (1993)
n.d. = no data

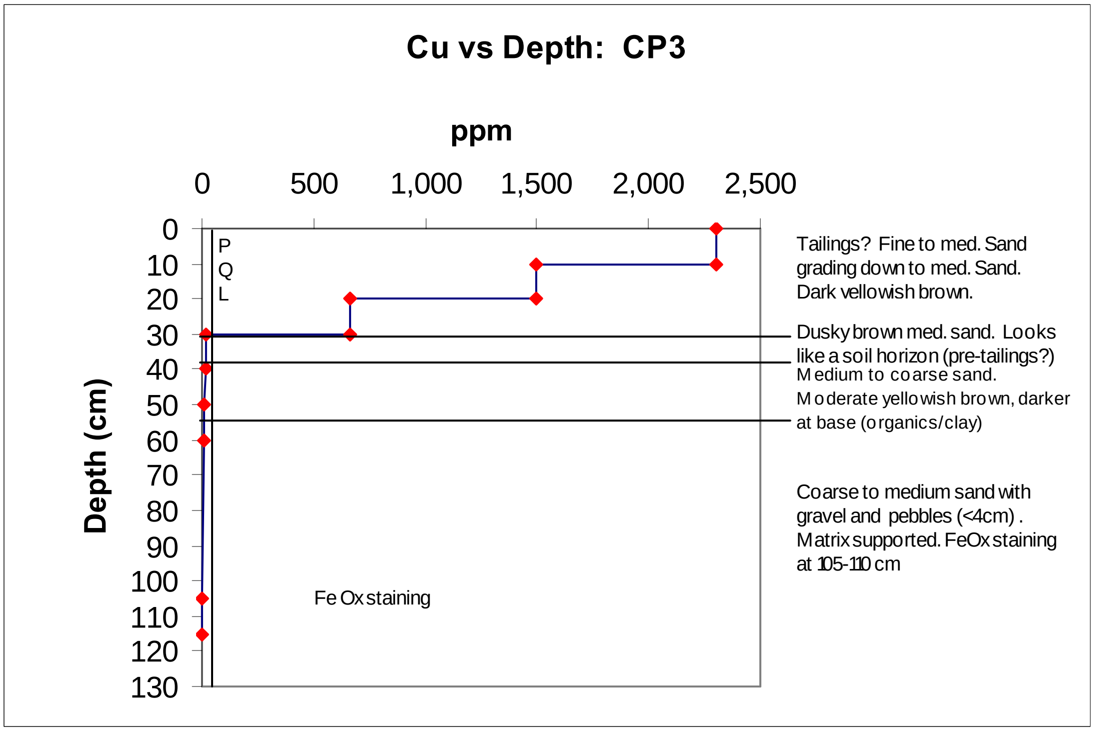

Figure 14. Example of vertical distribution of CoC (here Cu) showing declining concentration with depth in soil cores from the GRKO (from Moore and Woessner, 2001).

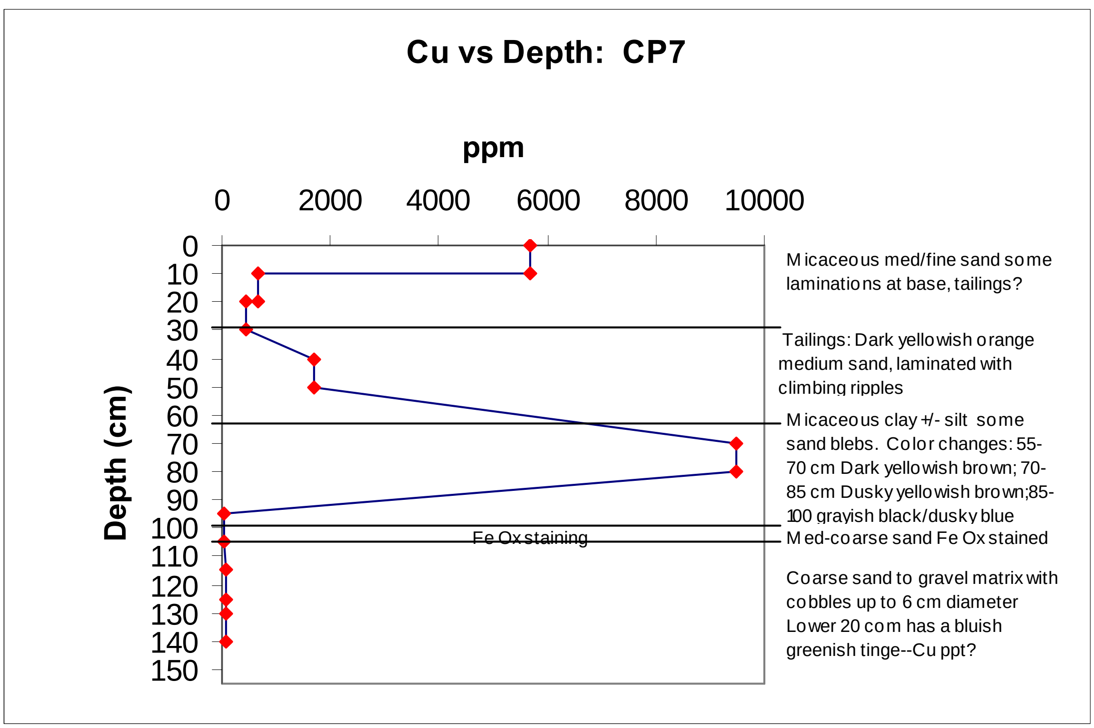

Figure 15. Example of vertical distribution of CoC (here Cu) showing highest concentration at depth in soil cores from the GRKO (from Moore and Woessner, 2001).

3.3.2 ***Injury Determination***

Injury determination for the riparian soils was based on historical and new sampling data for CoC concentrations in soils, historical and new phytotoxicity data, and new data on soil microbial functions. These data were evaluated against baseline concentration values.

3.3.2.1 Historic Riparian and Upland Soil Sampling

Several studies have been performed to characterize contamination of the GRKO (Appendix A. Annotation of Prior Studies). Screening level data for soil CoC were obtained in 1993, 1994, 1997, and 1998. In the State of Montana Injury Assessment, slickens were sampled and analyzed from riparian areas along Silver Bow Creek (Lipton *et al.*, 1993; LeJeune *et al.*, 1996). Various other studies in relation to characterization of contaminants and preliminary investigation of remediation options were also reported between 1987 and 1993 (Montana State University, 1989a, b; MultiTech, 1987; PTI, 1989; and CH2M Hill, 1991). Each of these studies focused on areas where slickens were evident at the soil surface. Varying sampling procedures were used: some analyzed only the upper 5 cm (2 in); others the upper 30 to 40 cm (12 to 15 in); and others, segments of soil core profiles at variable depths [e.g., 25 to 30 cm depth (10 to 12 in)]. Nevertheless, contaminant characteristics of tailings from these historical studies are applicable to the contaminants found in the riparian areas of the DOI lands. Although any given sample may vary with respect to concentration of analytes, in general tailings have elevated levels of one or more CoC and low pH (as illustrated by the median values; Table 7). Mean concentrations are markedly higher because of a few exceptionally high values.

Table 7. Compilation of historical analyses of slickens of the CFROU.

	As	Cd	Cu	Pb	Zn	pH
N	243	53	208	179	210	268
Minimum	4	1.8	4	16	19	2.0
Maximum	4,621	196	98,500	32,785	31,200	8.1
Arithmetic Mean	640	24	4,072	1,218	3,582	6.6
Median	379	14.4	1,863	498	2,413	4.6

Data compiled from: CH2M Hill, 1991; Lipton *et al.*, 1993; Montana State University, 1989a, b; MultiTech, 1987; and PTI, 1989

3.3.2.2 Recent Riparian and Upland Soil Sampling

The information for this section was derived from the technical reports by Moore and Woessner (2001) and Moore *et al.* (2001). The objectives of this work were to:

- characterize the type and spatial distribution of the CoC (As, Cd, Cu, Pb, and Zn) in the Clark Fork River floodplain, irrigated fields, and uplands;
- establish baseline concentrations for each CoC;
- identify CoC migration pathways; and
- compute the volume of soil having CoC above baseline and above toxic threshold concentrations identified as injurious.

3.3.2.2.1 ***Sampling Design and Locations***

In addition to the core samples described above (3.3.1 Baseline Metals Conditions, page 29), surface soil samples were collected from 126 locations at depths of 0 to 30 cm using a systematic grid sampling design (Figure 16). Sediment samples were taken from 11 locations from the main irrigation ditches running through the GRKO to determine the potential for contaminated sediment transport through irrigation. Surface soil samples were collected using a 15 cm (6 in) hand auger. Analytical and statistical methods were the same as those described above (3.3.1.1 Analytical Methods page 29). Additional sampling of surface soils for phytotoxicity and microbial process studies (15 cm depth composite auger samples) were analyzed to characterize CoC levels of 30 megaplots (see 3.3.2.4.1, below)

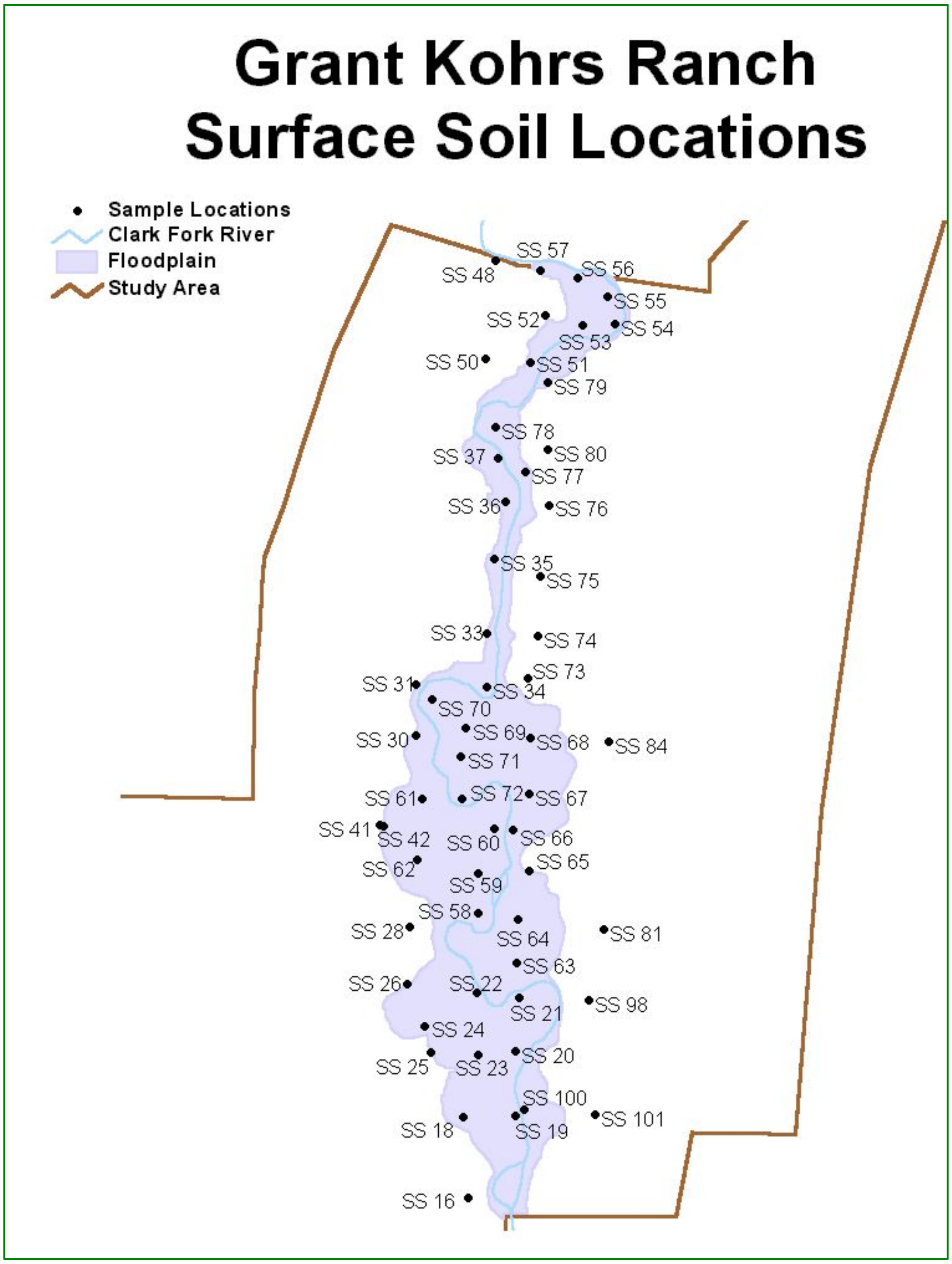

Figure 16. Location of surface soil sampling locations on the GRKO.

3.3.2.2.2 ***Findings - Riparian Zone***

Average concentrations of As, Cd, Cu, Pb, and Zn were substantially elevated over baseline concentrations (Table 8). The magnitude of contamination in this comparison is minimized as these data are based on values from the entire soil cores, including portions of the profile that were uncontaminated. The most contaminated soils approach 1,000-times baseline for Cu and 100-times baseline for As, Pb, and Zn. Cadmium levels are generally less pronounced, ranging up to 20-times baseline.

Table 8. Summary statistics of CoC concentrations (ppm) on the GRKO from soil profile samples.

Statistic / CoC	As	Cd	Cu	Pb	Zn
Baseline Concentrations	10	1	16	17	49
Mean	190	4	1,300	200	820
Magnitude of Elevation (mean/baseline)	19.0	4.0	81.2	11.8	16.7
MAD [a]	14	1	440	23	430
Inter-quartile range	220	3.8	1500	230	1,300
Max	1,600	20	15,000	1,600	4,500
Min	10	1.0	3.0	8.0	14
N	266	266	266	266	266

[a] Median Absolute Deviation

Stratigraphic descriptions of soil profiles illustrate the highly heterogeneous distribution of tailings and resulting CoC levels in the riparian zone. Though elevated levels often are found at the surface, it is common to find the highest concentrations deep within a profile (See Appendix A.5.4, pages A-93 through A-191 of Moore and Woessner, 2001). The heterogeneous distribution of slickens and buried tailings poses great difficulty in both the characterization of contaminants and the immediate manifestation of injury to biological resources. Plants established in relatively uncontaminated surface soils in the riparian area often encounter highly contaminated soils at some depth. Roots were frequently observed to be restricted to relatively uncontaminated zones in the soil profile, especially in situations where highly contaminated soils were found as buried lenses.

Irrigated fields on the GRKO received (and continue to receive) additional contamination in the irrigation waters. Suspended sediments were trapped in the ditches and were, over time, distributed onto the fields. Soluble substances flow onto the fields where they either percolate into the shallow groundwater or form a precipitate near the surface as evaporation occurs.

The geochemistry of the megaplot soils (2001 sampling) was determined by compositing soil samples from the upper 15 cm (6 in) of the soil profile. Four surface soil samples were collected using a soil hand auger. The concentrations of metals and arsenic in the megaplot soils had a wide range. Arsenic ranged from a low of 32 ppm to a high of 880 ppm, with a mean of 361 ppm (Table 9). The mean concentration of cadmium at all the sites was 7.2 ppm with a range from 3.2 ppm to 16 ppm. Copper ranged from a low of 600 ppm to a high of 7100 ppm, with a mean of 2579 ppm. The average concentration of lead was 381 ppm, with a low of 110 and a high of 1100. Zinc had a mean concentration of 1592 ppm with a low of 720 ppm and a high of 2900. The mean pH for all the samples was 6.7 with a range from 4.2 to 8.2. Organic carbon averaged 4.4%, but ranged from a low of 0.9% to 14.6%.

Table 9. Descriptive statistics of Megaplot soil samples from 15 cm depth.					
Analyte	**Mean**	**Std. Dev.**	**Number**	**Minimum**	**Maximum**
As (ppm)	361	224	30	32	880
Cd (ppm)	7.2	3.1	30	3.2	16
Cu (ppm)	2579	1633	30	600	7100
Pb (ppm)	381	212	30	110	1100
Zn (ppm)	1592	563	30	720	2900
pH	6.7	1.0	30	4.2	8.2
Org. C (%)	4.4	3.1	30	0.9	14.6

The concentrations of CoC in surface soils (top 30 cm) of the GRKO, that were near baseline concentrations, reflect the heterogeneity described from soil profile data. Though some surface soils had baseline concentrations of CoC, other samples were highly contaminated. Maximum CoC concentrations in the surface soils ranged from 12x above baseline for Cd to 525x above baseline for Cu (Table 10).

Table 10. Summary statistics of CoC concentrations (ppm) on the GRKO from soil samples (30 cm depth).					
Statistic / CoC	**As**	**Cd**	**Cu**	**Pb**	**Zn**
Baseline Soil Concentrations	10	1	16	17	49
Median	46	2.4	420	77	610
MAD [a]	27	1.3	360	78	490
Inter-quartile range	180	3.4	1340	230	1,100
Max	940	12	8,400	920	3,200
Min	13	1.0	29	16	43
N	107	107	107	107	107
[a] Median Absolute Deviation					

Deposition of tailings in the floodplain was patchy, such that current levels of CoC vary considerably both horizontally across the landscape and vertically in the soil profile. The high degree of spatial heterogeneity complicates full characterization of contaminants. The sampling designs used in the 2000 and 2001 field seasons provided nine paired sample points separated by 5 m. These data underscore the level of heterogeneity: of the CoC, only As concentrations were similar between pairs; Cu, Zn, and pH values showed no relationship among paired samples (
Figure 17). Spatial statistical tools, such as krieging, commonly used to interpolate concentrations between sample points are not useable with the level of heterogeneity observed here.

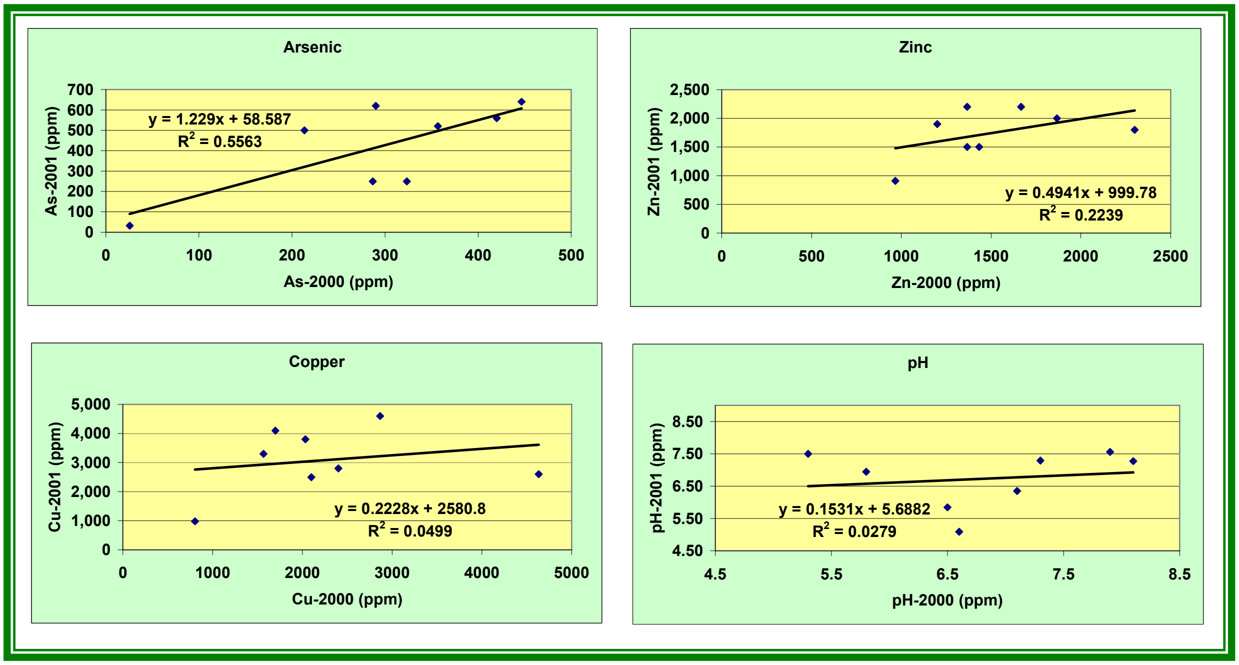

Figure 17. Indication of spatial heterogeneity from nine paired plots separated by 5 m.

3.3.2.2.3 <u>Findings - Irrigation Ditches</u>

Concentrations of CoC in sediments from the two major irrigation ditches on the GRKO were elevated substantially above baseline soil levels (Table 11). Though the median for several of the CoC is greater in the ditch sediments than the surface soils (Table 10), the maximum concentrations are generally lower. This, along with the lower MAD, indicates that the ditch sediments exhibit less variability than do the surface soils.

Element concentrations from each surface soil sample were divided by the respective baseline concentrations to determine the magnitude to which concentrations were elevated above baseline. Therefore, these values are directly comparable among elements. Spatial distribution of CoC concentrations normalized to baseline demonstrates the strong tendency for high concentrations of contaminants in surface soils to be within the floodplain (See Plates 7 through11 in Moore and Woessner, 2001). Outside of the floodplain, concentrations are relatively lower, generally <10-times greater than baseline.

Table 11. Summary statistics of CoC concentrations (ppm) on the GRKO from soil sediment samples from ditches.

Statistic / CoC	As	Cd	Cu	Pb	Zn
Baseline Soil Concentrations	10	1	16	17	49
Median	65	6.1	830	140	1,500
MAD [a]	14	1.0	110	20	400
Inter-quartile range	39	2.0	330	70	600
Max	130	11	2,400	280	2,500
Min	27	4.9	400	78	1,100
N	9	9	9	9	9

[a] Median Absolute Deviation

3.3.2.2.4 Findings - Upland Areas

Six sampling sites were established in the non-irrigated upland terraces of GRKO to investigate the possible presence of aerial fallout of CoC from smelter emissions. The highest elemental concentrations were in the upper 5-10 cm in five[8] of six site profiles (Moore *et al.*, 2001). The profiles also had lower pH values in the upper intervals. This distribution is best explained as the aerial deposition of CoC from smelting operations in Anaconda. Relatively constant CoC concentrations found at depth were used to establish a pre-deposition reference concentration. For elements that were below the PQL, the PQL was used as a reference value. Arsenic was below detection of 10 ppm in the lower levels of the profiles for all the profiles, establishing a reference value of 10 ppm. This is a high value because values could be anywhere below 10 ppm. The contamination index (mean surface value/reference value) for As was 4.8- to 6.0-times above the inferred pre-smelting values. In other words, there is about 4 1/2 times as much arsenic in the surface soils as would be expected if air fall did not occur. Similar contamination indices occurred for other elements. Soil pH is decreased by nearly two pH units compared to the reference soils deeper in the profiles.

3.3.2.3 Historic Phytotoxicity Tests

Several prior phytotoxicity studies have been performed on slickens in the CFROU. These include studies conducted for the RI/FS (Montana State University *et al*., 1989a), the State of Montana Injury Assessment (Lipton, *et al*., 1993), and an academic study (Rader *et al.*, 1997).

The Streambank Tailings and Revegetation Study (STARS), a component of the Silver Bow Creek RI/FS, was initiated to develop remedies for *in situ* treatment of tailings deposited along Silver Bow Creek (Montana State University *et al*., 1989a). Greenhouse phytotoxicity tests were performed on six slickens soil samples. The test species were selected for their tolerance to acidic soils with high metal concentrations. The authors noted that no native plants had evolved tolerance mechanisms to cope with the conditions found on slickens, thus no native species were included in the tests. Nevertheless, even the tolerant species used in their tests had 100% failure (i.e., all plants in all trials either failed to germinate or died shortly after emergence).

Four slickens samples were evaluated for phytotoxic responses for the State of Montana Injury Assessment (LeJeune, *et al.*, 1996; Lipton, *et al*., 1993). Alfalfa, lettuce, wheat, and hybrid poplar were used as test species. In two of the samples, germination and emergence of the herbaceous species was completely inhibited; in one sample emergence ranged from 0- to 25% for the three species; and in the fourth sample emergence ranged from 5- to 75%. Of those seedlings that survived, growth was significantly less than controls for alfalfa and lettuce in all samples, and was significantly less than controls in three of the four samples for wheat. Mortality of hybrid poplar was 100% in three of the four samples and was 40% in the fourth sample. Growth of shoots and roots in the fourth sample was inhibited by approximately 75% compared to controls. All four samples were classified as severely phytotoxic.

Rader *et al*. (1997) tested slickens soils from the GRKO at various dilutions (made with uncontaminated soil) using barnyard grass (*Echinochloa crusgalli*), lettuce (*Lactuca sativa*), radish (*Raphanus sativus*), and redtop bentgrass (*Agrostis gigantea*). They found that root growth was the most sensitive endpoint. In 100% slickens material, all four species, even the generally metals tolerant redtop bentgrass, were inhibited. Barnyard grass had limited emergence in treatments having 75% and 50% slickens with the remaining portion of the test soil made up with uncontaminated soil. Lettuce has a very low level of emergence at the 25% slickens level. Radish and redtop bentgrass emergence occurred only at slickens concentrations of 12.5% and less. Comparing root growth of emerging plants, barnyard grass was the most sensitive species.

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[8] Site F-2 (see Moore *et al.*, 2001 for map of location) was excluded from the analysis because of the overall very low values, likely due to the coarse grain size.

3.3.2.4 Recent Phytotoxicity Tests

Phytotoxicity tests were performed in 2000 and 2001 on soils collected from the GRKO. The tests were completed to:

- characterize the magnitude of phytotoxic response to contaminants in soils from the GRKO;
- characterize the dynamic relationships of contaminants in buried tailings in terms of phytotoxic potential; and
- provide linkage of results with the chemistry, microbial ecology, and vegetation data of the affected areas (i.e., megaplot sites).

3.3.2.4.1 Sampling Design and Locations

Sampling locations were identified using a stratified random sampling method structured to span the range of CoC concentrations on the GRKO. Copper and Zn concentrations from 30-cm soil cores [previously analyzed and subsequently reported in Moore and Woessner, 2001] were regressed to facilitate selection of representative sites with minimal outlying variation of CoC. Sample locations were ranked and segregated into three classes designated as High-, Intermediate-, and Low-CoC Loading before selecting random sites. The sites were re-located in the field using a Trimble GPS unit.

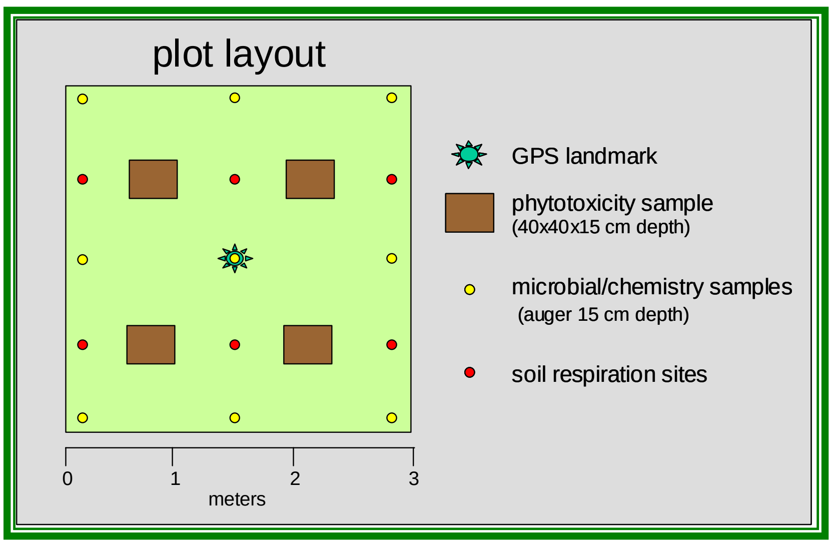


Figure 18. Layout of sample area for samples from 2000.

The sample design was modified for 2001 to accommodate co-located sampling of vegetative cover and aboveground plant growth (Figure 19).[9] Sample identification codes (i.e., MP-01 through MP-100) for the 30 samples in 2001 were centered on the corresponding SS-xxx code from the previous year's surface soil sampling locations (See Figure 16 and Appendix C. Cross-list of surface soil sample codes).

[9] See Gannon and Rillig, 2002 for description of the stratified random selection process used to identify candidate sample locations.

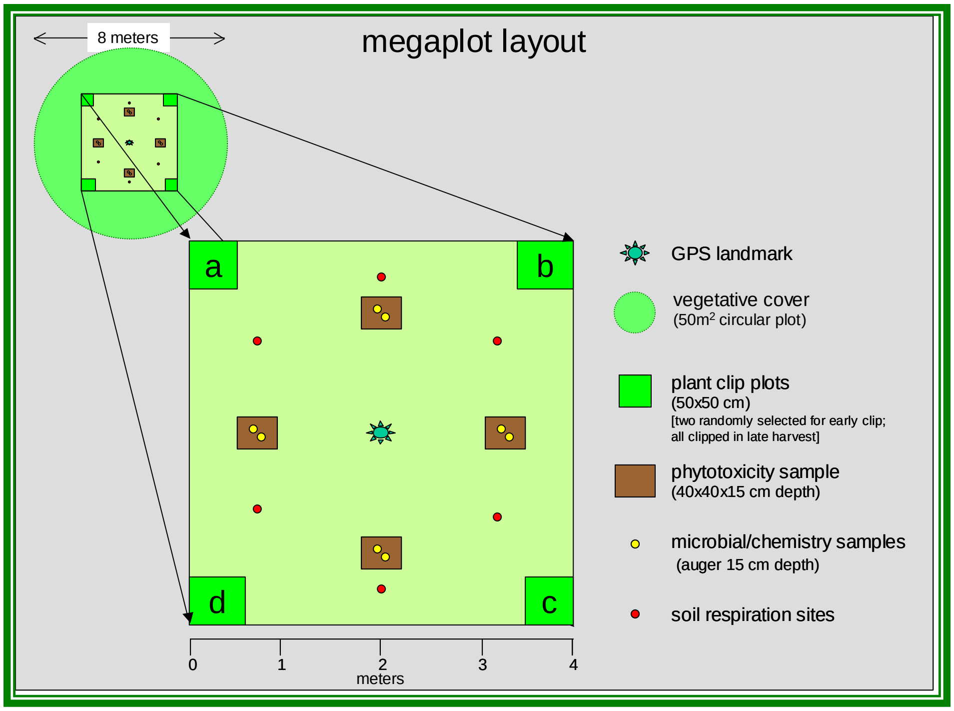


Figure 19. Layout of sample area for samples from 2001.

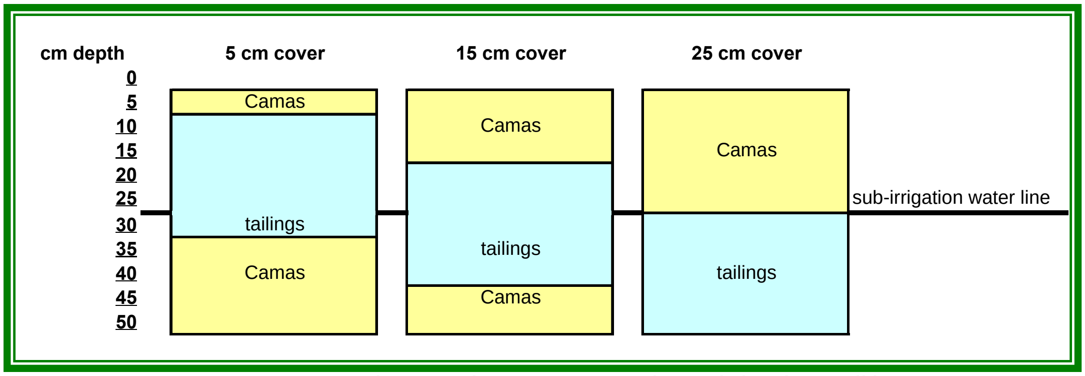
3.3.2.4.2 Materials and Methods

The ASTM E1963-98 *Standard Guide for Conducting Plant Toxicity Tests Annex 1 Seedling Emergence* and *Annex 4 Woody Plant Species Growth and Development* (ASTM, 2000) was used for this project. This Guide provides descriptions of steps used in testing environmental (i.e., site) samples to determine phytotoxicity vis-à-vis reference samples. Plant performance was evaluated in comparison to endpoints measured using negative controls. Quantitative data (counts, height or length, and mass;) as well as qualitative observations were gathered during and at the conclusion of the test. Growth in Negative and Positive Controls followed nominal patterns during the course of the study. Measurements of plant performance were analyzed using non-parametric statistical tests (e.g., Kruskal-Wallis) to ascertain significant differences among treatments (Kapustka *et al*., 1995).

The tests were conducted on 15 samples in 2000 and 30 samples in 2001 collected from the GRKO. Artificial soil was used for negative and positive controls for each test. Four test species (alder, alfalfa, dogwood, and sedge) were used in 2000 and two species (alfalfa, alder) were used in 2001. Additional laboratory tests were conducted using tailings to characterize the phytotoxic response of test plants exposed to tailings buried at various depths. Field studies examining the response of plants exposed to tailings buried at various depths were also performed.

Two 0.5 m x 0.5 m = 0.25 m^2 plots in each of the 30 megaplots (see Figure 19) were selected randomly for collection of spring-time above-ground plant growth. The first harvest occurred between late-May and early-June 2001. All four plots in each megaplot were clipped late in the growing period (late-July to mid-August) to obtain measures of regrowth (from the previously clipped plots) and maximum standing crop from the two that were not clipped initially. Current year's growth was clipped at ground-level and sorted into forb and graminoid growth forms. Clipped plant material was transported to Missoula for drying. Oven dry weights were recorded. All field lab work on this portion of work was performed under the direction of Peter Rice, University of Montana, Missoula.

Laboratory tests using buried slickens were performed in 10 cm (4 in) diameter PVC pipes cut to 50 cm length. Three treatments consisting of 5-cm, 15-cm, and 25-cm depth of clean soil laid over 25 cm of tailings were prepared; the base was filled with 20-cm, 10-cm and 0-cm clean soil respectively (Figure 20). Three replicates of each treatment depth were planted with alfalfa seeds (16 each), alder seedlings (one each), Bebb willow seedlings (one each), sedge plugs (one each), or wheat seeds (nine each). One set (three treatments, three replicates, five test species) was subjected to surface irrigation; another set was sub-irrigated.



(Camas is an uncontaminated riverine soil.)

Figure 20. Schematic design of buried tailings laboratory experiments.

Three slickens areas (near MP-071, MP-065, and MP-060) were selected as sites for installation of field plots. Five 1m x 1m surfaces devoid of vegetation and at nominally the same elevation and exposure conditions were marked within each site. The surficial slickens were removed from these 1m x 1m plots to depths of 5-, 10-, 15-, 20, or 25 cm (Figure 21). Plexiglas sidewalls and divider panels or corresponding depths were placed in each pit. Uncontaminated riverine sandy soil from the Clark Fork River basin was added as fill material at the corresponding depths.

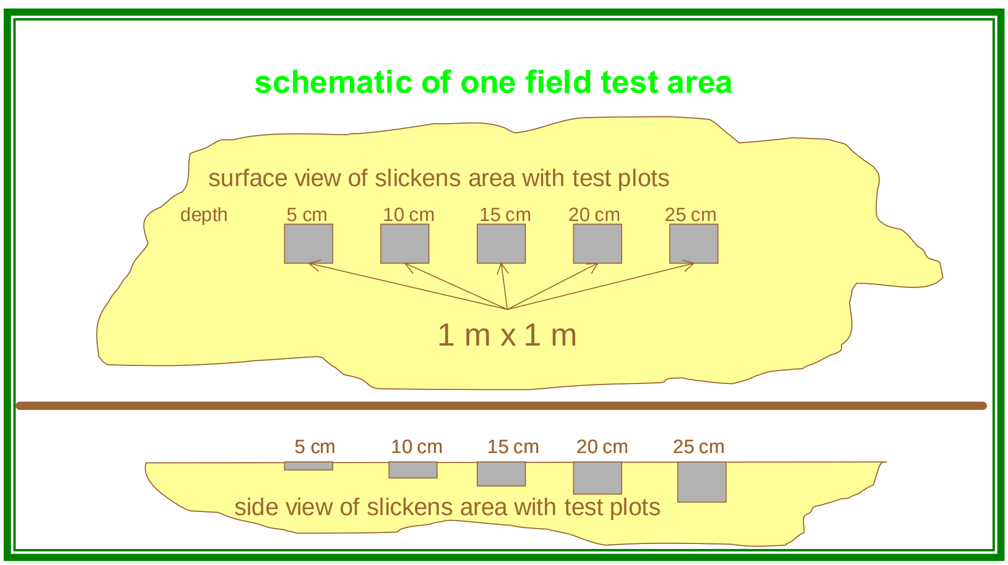


Figure 21. Schematic design of buried tailings field studies.

Alder, willow, and sedge plants (ten each) were removed from "Conetainers" and planted in rows separated by divider panels in each plot.[10] Shoot height and number of branches were recorded for each individual. A tent made of fine-mesh plastic window screening was constructed over each plot to protect the plants from deer, rodents, and insects.

Plots were irrigated with Clark Fork River water immediately following planting. Watering continued on a daily basis for one week. During the second week, watering was reduced to every other day. During the third week, plots were watered twice. Thereafter, no irrigation water was added.

3.3.2.4.3 <u>Findings</u>

The endpoints that showed the greatest phytotoxic response were mean nodule number (in alfalfa)[11], root dry weight, total dry weight per pot, and total dry weight per plant (Table 12). The endpoints that showed the least phytotoxic response were shoot appearance and color in the first or second week.

Table 12. Rank of endpoints responsiveness as calculated using mean phytotoxicity scores across four test species.

Endpoint [a]	Phytotoxicity Score [b]	Endpoint [a]	Phytotoxicity Score [b]
Mean Nodule Number	3.20	Mean Root Length (mm)	0.91
Mean Net Growth - Leaf Number [c]	2.53	Mean Shoot Height (mm)	0.87
Root Dry Weight (g)	2.42	PE 14 Shoot Appearance	0.87
Total Dry Weight (g)	1.78	PE 14 Count	0.83
Root Appearance	1.73	Shoot Appearance	0.72
Shoot Dry Weight (g)	1.72	PE 14 Shoot Color	0.60
Total Dry Weight per Plant (g)	1.60	PE 7 Shoot Color	0.58
PE 7 Height	1.33	PE 7 Shoot Appearance	0.40
Shoot Color	1.27	Harvest Count	0.38
PE 14 Height	0.93	PE 7 Count	0.36
Root Color	0.91	Emergence Count	0.23

[a] PE = Post-emergence. [b] Phytotoxicity Scores are unitless values between 0 and 4 (See text).
[c] applicable only to buried tailings laboratory tests with seedlings.

Phytotoxicity scores also were used to classify the magnitude of phytotoxicity observed for the 45 soils (Table 13). Soil samples MT-01 through MT-15 were tested with four species (alfalfa, alder, dogwood, and sedge); soil samples MP-18 through MP-100 were tested with two species (alfalfa and alder). The compiled results demonstrate that seven samples were severely phytotoxic, 12 were highly phytotoxic, 18 were moderately phytotoxic, and six were mildly phytotoxic, and two were scored as non-phytotoxic.

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[10] Alfalfa was seeded in a divided area of each plot. However, high temperatures and rapid drying of the surface of the soils prevented emergence of nearly all alfalfa seedlings. Consequently, no data on alfalfa was obtained from these field studies.

[11] Nodules in legumes result from the formation of a symbiotic association of bacteria (of the genus *Rhizobium*) and the host plant. Shortly after the bacteria are encapsulated in a developing root hair, the colonized region enlarges and undergoes several developmental and biochemical transformations. The nodules become the site of fixing atmospheric nitrogen (N_2) into ammonia (NH_3). The nitrogen fixed in this manner, supplies approximately 70% of the N requirement of legumes, and upon decomposition become an important nutrient supply to soil. Without functional nodules, the plants must derive all of their N requirements from the soil.

Nodules of a different nature, referred to as actinorhizal symbionts of the genus *Frankia*, also form on a number of woody species including alder. These nodules differ anatomically and biochemically from rhizobial types, but also accomplish dinitrogen fixation. The actinorhizal symbionts generally are more prominent in natural plant communities, whereas rhizobial symbionts are most important in agricultural settings.

Soil CoC concentrations, with the exception of Cd, were generally greatly elevated compared to baseline levels reported by Moore and Woessner (2001). The concentrations of As, Cu, and Zn were also substantially greater than the upper ranges of phytotoxicity threshold values[12] (Figure 23). Concentrations of Pb were generally below the levels known to evoke phytotoxic responses. In that a given sample often contained elevated levels of more than one CoC, and phytotoxicity of these substances is known to be influenced by pH, our focus was on As, Cu, Zn, and pH.

Phytotoxicity endpoints were evaluated across the range of CoC concentrations. A weighting factor that adjusted concentrations of As, Cu, and Zn by pH was used (Kapustka *et al.*, 1995). Significant relationships were evident for growth and pH-adjusted metal concentrations. Total dry weight per plant regressed against the summed pH-adjusted metal concentrations indicated alfalfa was the most responsive species, followed by dogwood, then alder, and finally sedge (see Figures 7 and 8 in Kapustka, 2002). Because of the larger sample size, relationships demonstrated for alfalfa and alder are particularly strong.

Table 13. Phytotoxicity scores compiled for tests by soil sample.

Sample ID	Phytotoxicity Category	Phytotoxicity Score	Sample ID	Phytotoxicity Category	Phytotoxicity Score
MT-01	Mildly Phytotoxic	0.45	MP-036	Moderately Phytotoxic	0.57
MT-02	Moderately Phytotoxic	0.90	MP-042	Moderately Phytotoxic	0.70
MT-03	Mildly Phytotoxic	0.42	MP-051	Severely Phytotoxic	2.03
MT-04	Mildly Phytotoxic	0.18	MP-053	Severely Phytotoxic	2.03
MT-05	Highly Phytotoxic	1.33	MP-056	Highly Phytotoxic	1.45
MT-06	Severely Phytotoxic	3.53	MP-057	Moderately Phytotoxic	0.95
MT-07	Moderately Phytotoxic	0.74	MP-058	Highly Phytotoxic	1.31
MT-08	Highly Phytotoxic	1.06	MP-059	Highly Phytotoxic	1.13
MT-09	Moderately Phytotoxic	0.85	MP-060	Highly Phytotoxic	1.83
MT-10	Severely Phytotoxic	3.21	MP-062	Highly Phytotoxic	1.40
MT-11	Highly Phytotoxic	1.09	MP-065	Mildly Phytotoxic	0.36
MT-12	Moderately Phytotoxic	0.82	MP-066	Severely Phytotoxic	2.29
MT-13	Highly Phytotoxic	1.17	MP-067	Moderately Phytotoxic	0.69
MT-14	Moderately Phytotoxic	0.52	MP-068	Moderately Phytotoxic	0.62
MT-15	Highly Phytotoxic	1.19	MP-069	Moderately Phytotoxic	0.74
MP-018	Moderately Phytotoxic	0.54	MP-070	Highly Phytotoxic	1.90
MP-019	Mildly Phytotoxic	0.45	MP-071	Severely Phytotoxic	2.29
MP-021	Moderately Phytotoxic	0.65	MP-072	Moderately Phytotoxic	0.59
MP-022	Mildly Phytotoxic	0.34	MP-077	Moderately Phytotoxic	0.77
MP-024	Moderately Phytotoxic	0.57	MP-078	Moderately Phytotoxic	0.95
MP-033	Mildly Phytotoxic	0.12	MP-079	Highly Phytotoxic	1.26
MP-034	Mildly Phytotoxic	0.34	MP-100	Moderately Phytotoxic	0.51
MP-035	Severely Phytotoxic	2.18			

If data from the atypical soil samples in terms of organic matter (MP-018, MP-024, MP-056, MP-062, and MP-065) and pH (MP-079) are censored from the analyses, the correlation coefficient (R^2) for the alfalfa study rises from 0.650 to 0.756 (graph not shown).

[12] Phytotoxic threshold concentration ranges used in Figure 23 are derived from various publications including Lipton *et al.* (1993), Kabata-Pendias and Pendias, (1992). Eco-SSLs are soil concentrations developed by the US EPA for use in screening contaminated sites. The values are considered the point above which phytotoxicity may be a concern. The US EPA anticipates publishing the values sometime in 2002.

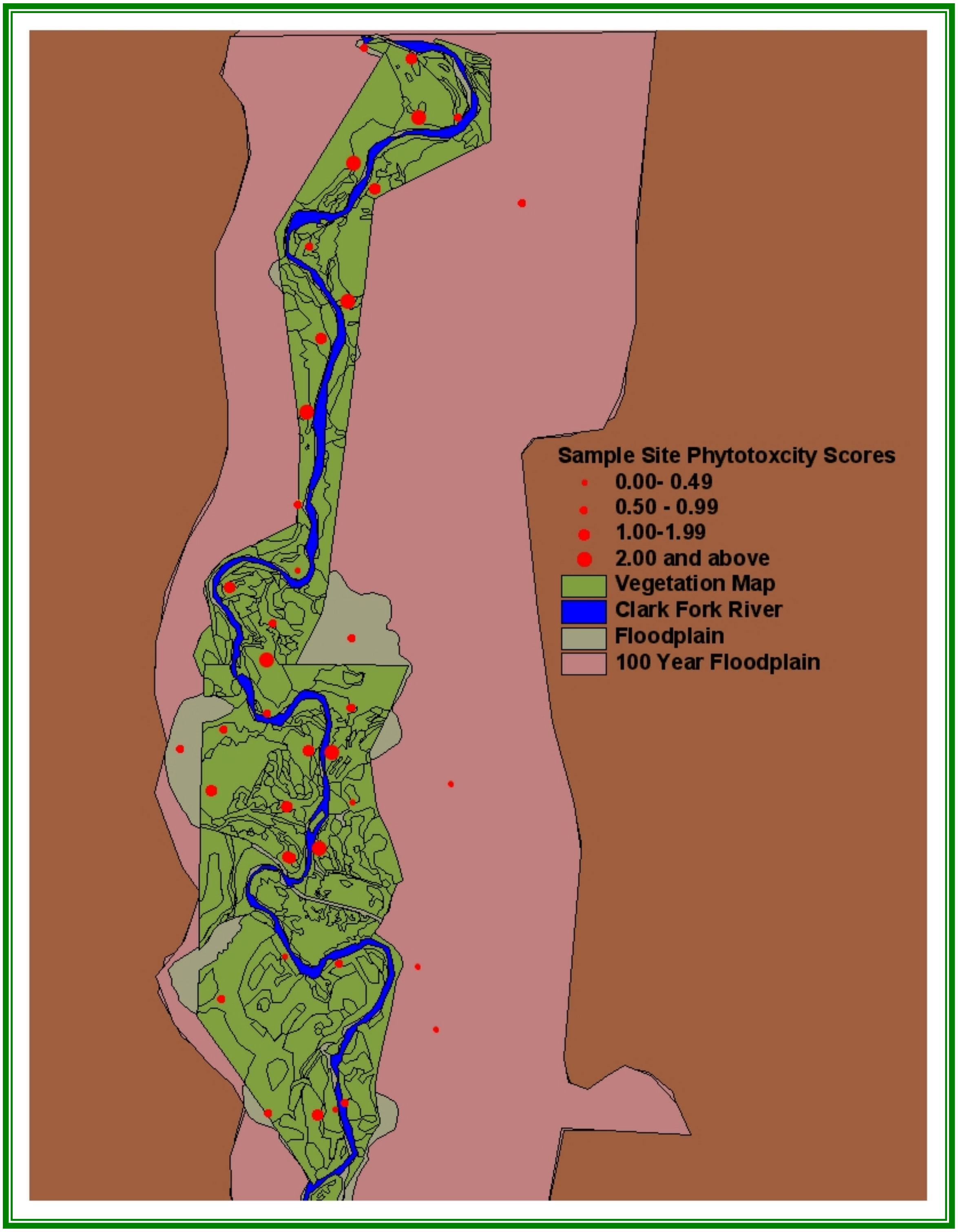

Figure 22. Relative phytotoxic response in relationship to the GRKO floodplain.

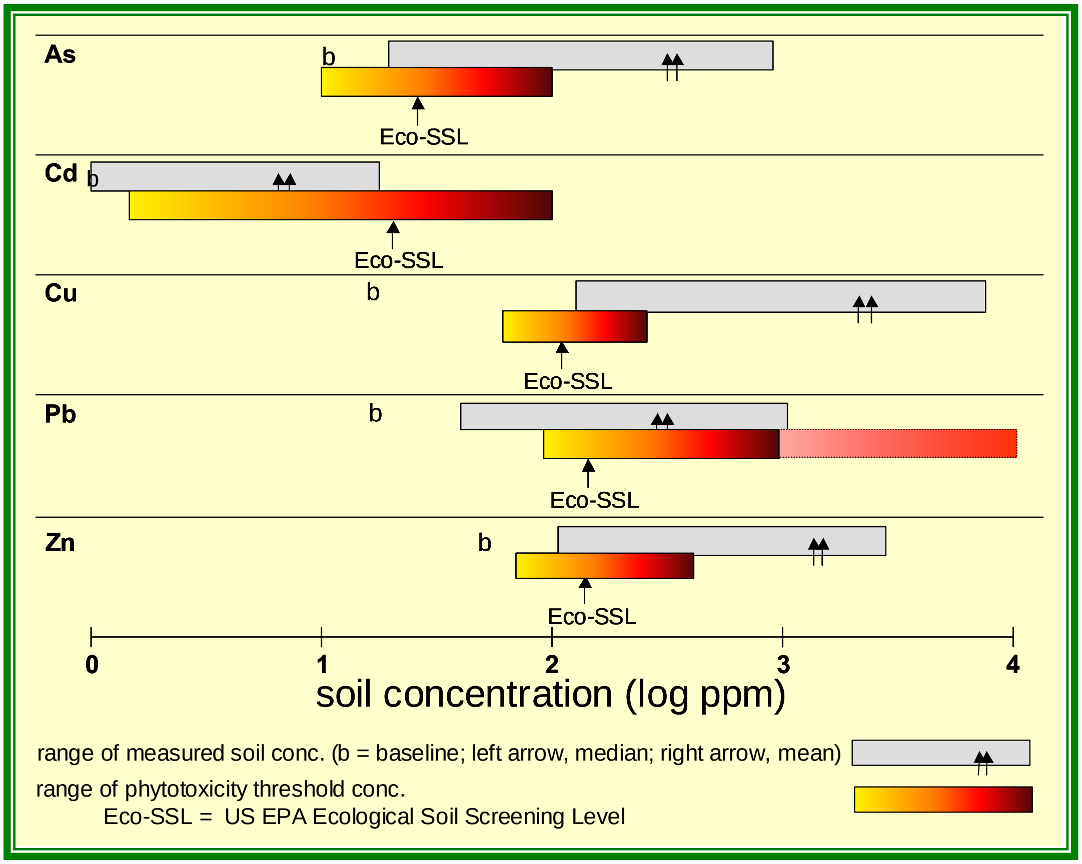

Figure 23. Comparison of measured soil CoC concentrations in GRKO samples used in phytotoxicity tests and the range of phytotoxic threshold concentrations.

Levels of As, Cu, and Zn in surface soils consistently exceeded published phytotoxicity thresholds. A weighting factor, which incorporated the influence of pH, was used to relate concentrations to phytotoxic responses. This unitless factor ranged from 0.9 to 14.6 for the GRKO surface samples. Visual inspection of the scatterplots (for alfalfa and alder) revealed relatively large variance at the low range of pH-adjusted metal concentration and relatively lower variance as the pH-adjusted metal concentration increased. Also, the data suggested a trend of decreasing maximum plant growth as the pH-adjusted metal concentration rose. The basic concept embodied in the "Law of the Minimum" expressed by Liebig (1840) and refined by Blackman (1905) explains this common biological property. An environmental factor governs the maximum response attainable by an organism; at any interval along a parameter gradient, other variables may curtail attainment of the potential. For example, at low concentrations of a toxicant, an organism may be deterred from attaining its growth potential by unfavorable temperature, moisture, nutrients, etc. The approach used to elucidate the limits on growth imposed by the CoC was to divide the range of pH-adjusted metal values into uniform intervals and to identify the maximum value of each interval. The nominal range of pH-adjusted metal concentration (0 to 15) was divided into equal intervals or bins of 1.5 units each. To eliminate bias that might occur in selecting bins, the start points were varied from –1.50 to +1.50 at 0.25 units; this resulted in 13 selections of interval bins. A polynomial (non-linear) regression was run using these maxima. Statistically significant and biologically relevant phytotoxicity occurred at pH-adjusted As, Cu, and Zn levels above 3.0. The pH-adjusted metals concentration explained 85.5% of the observed variance in maximum plant growth (Figure 24).

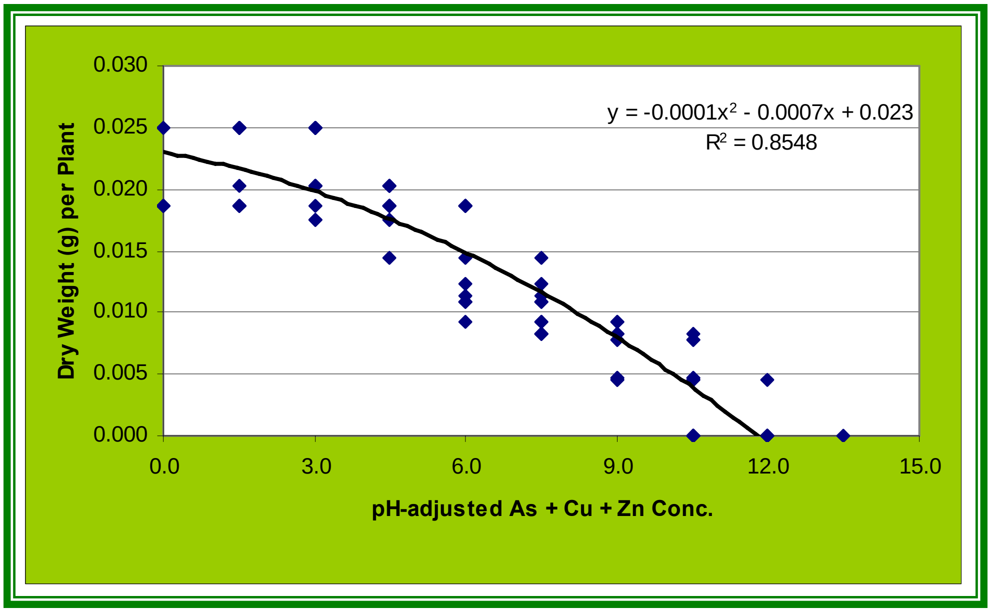

Figure 24. Polynomial regression of pH adjusted metal concentrations and maximum dry weight per plant for alfalfa.

The response of alder plants in the tests conducted in 2001 also demonstrated strong negative relationships to pH-adjusted metal concentrations. Survival, generally a poorly responsive endpoint in short-term toxicity tests, did show a sharp decline with pH-adjusted values above 12. Very strong negative relationships occurred for the other quantitative endpoints including shoot height, net number of leaves, net number of branches, increase in root length, and total plant mass. As with alfalfa, scatterplots suggested a maximal value for many endpoints. Total plant dry weight regressed against pH-adjusted metals concentration showed a strong negative relationship for maximum growth, with 79.9% of the variance explained by the CoC (Figure 25).

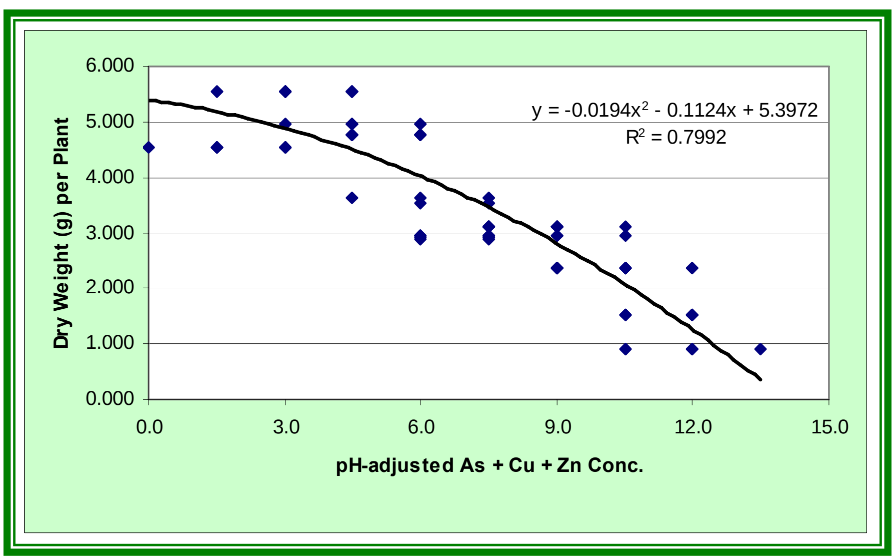

Figure 25. Polynomial regression of pH adjusted metal concentrations and maximum dry weight per plant for alder.

3.3.2.5 Growth and Re-growth of Herbaceous Vegetation in the Field

Considerable variability in phytomass occurred among subplots; a few high productivity plots skewed the mean higher than the median values (Table 14). The highest phytomass measured was from graminoids on plots with very high organic matter.

The quantity of phytomass was significantly lowered by CoC. The pH-adjusted metal concentration was inversely related to phytomass (Table 15; Figure 26). In each group, the forbs were more responsive to pH-adjusted metal concentrations than were the graminoids. Consequently, the combined values (herbaceous phytomass) were often intermediary between forb and graminoid responses. However, for the second harvest and for the regrowth measurements, the combined herbaceous phytomass exhibited slightly stronger relationships to pH-adjusted metal concentrations. When soils with high organic matter and high pH were censored from the dataset, the strength of the relationship was increased considerably.

Table 14. Summary statistics for growth, regrowth, and productivity (phytomass g/0.25 m^2 clip-plot) from megaplots in 2001.

Life-form	Forb	Graminoid	Herbaceous
first harvest[1]			
Minimum	0.00	0.02	0.02
Maximum	10.96	64.36	64.38
Mean	1.92	13.88	15.80
Median	0.97	9.13	11.63
re-growth[2]			
Minimum	0.00	0.00	0.00
Maximum	30.87	165.60	165.60
Mean	5.56	19.43	24.99
Median	2.41	10.60	15.45
second harvest[3]			
Minimum	0.00	0.00	0.00
Maximum	50.75	215.74	215.74
Mean	9.25	34.41	43.66
Median	7.77	20.54	31.39
productivity[4]			
Minimum	0.00	0.00	0.00
Maximum	41.82	229.96	229.98
Mean	7.35	32.47	39.82
Median	3.86	20.11	28.83
standing crop[5]			
Minimum	0.00	0.00	0.00
Maximum	33.59	222.85	222.86
Mean	8.30	33.44	41.74
Median	7.21	17.97	30.14

[1] Harvest occurred from 29 May through 8 June 2001.
[2] Phytomass of sub-plots that grew between the first and second harvest.
[3] Harvest occurred from 25 July through 14 August 2001.
[4] The sum of phytomass from the first and second harvest.
[5] Standing crop is the mean of second harvest and productivity values.

Table 15. Correlation coefficients (R^2) for phytomass measurements versus pH-adjusted metal concentrations.					
Component	**First Harvest**	**Second Harvest**	**Regrowth**	**Productivity**	**Standing Crop**
All Data					
Forbs	0.2859	0.1560	0.2478	0.2851	0.2984
Graminoids	0.1444	0.1232	0.0572	0.0831	0.1048
Herbaceous	0.2232	0.2079	0.1295	0.1630	0.1916
Censored Data					
Forbs	0.4129	0.2222	0.2912	0.3534	0.3960
Graminoids	0.1871	0.1615	0.0781	0.1128	0.1435
Herbaceous	0.3351	0.3055	0.3121	0.3486	0.3807

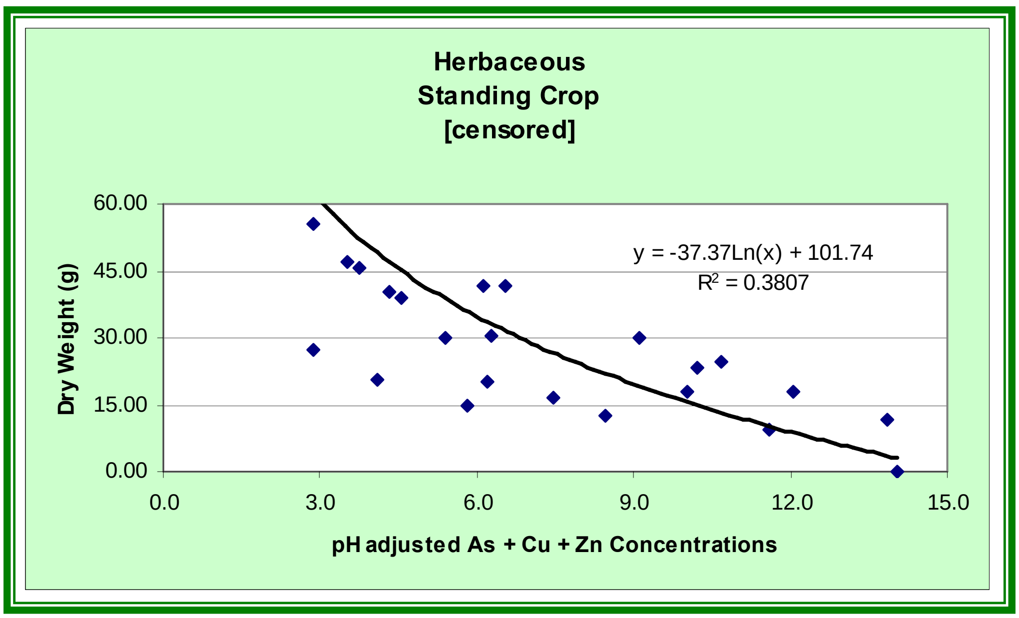

Figure 26. Relationship between herbaceous standing crop in the GRKO riparian area and pH-adjusted metal concentrations.

Many environmental factors affect the level of plant growth in the field. The concurrent influence of multiple factors contributes to the variability observed in the clip-plot data. When the maximum values across intervals are considered, the pH-adjusted metal concentrations explained 70% of the observed variability (Figure 27).

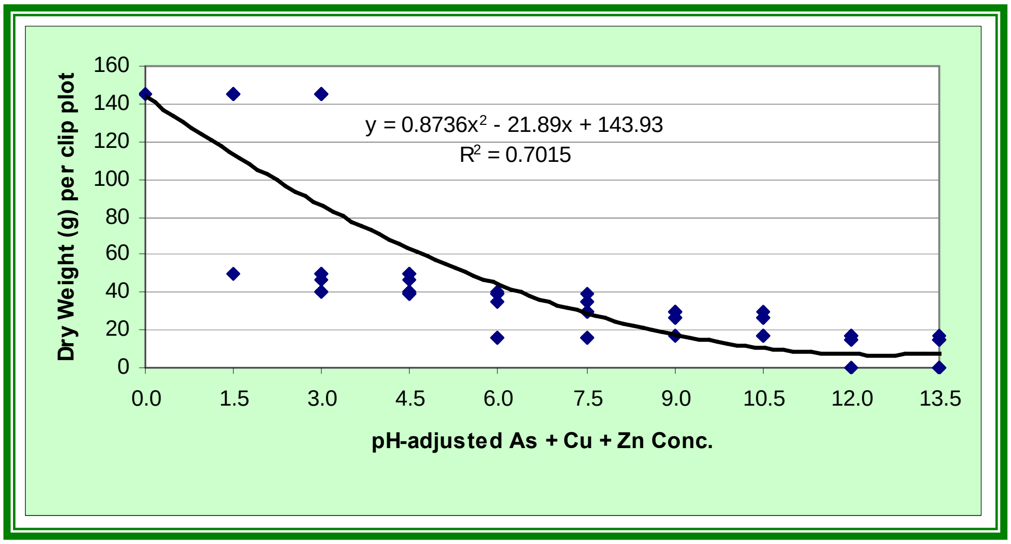

Figure 27. Maximum growth potential expressed in relation to pH-adjusted metals.

Data from the standardized phytotoxicity tests using alfalfa conducted in the laboratory and the measurements of herbaceous phytomass in clip-plots from the same megaplots were compared using linear regression (Figure 28). Outliers as discussed above (high organic matter and high pH) were removed from the data sets. One additional outlier, which had an approximately 4-fold greater phytomass than the remaining data values, was also removed. This strong relationship between phytotoxic response (plant weight) and herbaceous standing crop validates the separate relationships described above between pH-adjusted metal concentrations and phytotoxicity and phytomass in the field.

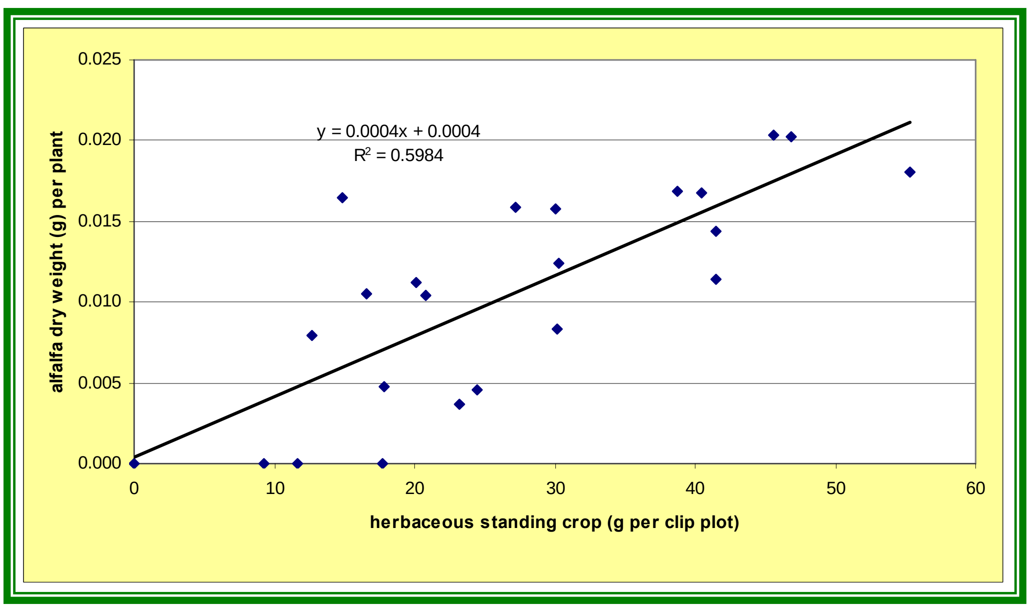

Figure 28. Linear regression of herbaceous standing crop from clip plots versus alfalfa phytomass per plant from laboratory toxicity tests from corresponding megaplot samples.

Soil CoC concentration data and pH values from soil core profiles were used to calculate the pH-adjusted metals value for each depth interval. Equations from the maximum growth potential plots (see Figure 24, Figure 25, Figure 27) were used to predict the phytotoxic response based on the pH-adjusted metals value for each depth interval. The toxicity threshold, defined as the value resulting in $\geq$10% reduction in growth, was the pH-adjusted value ~3.0 (Figure 29). Data were accumulated across all soil cores for each depth. Values for each depth interval were expressed as the proportion of cores exceeding the phytotoxicity threshold at that depth (Figure 30). For the GRKO riparian area, the probability of encountering phytotoxic conditions in surface soils (0 to 15 cm depth) was 71 to 76% for alder, 81% for alfalfa, and 86 to 91% for herbaceous productivity. Multiplying the riparian area (i.e., 51.42 ha; 127.2 ac) by the probability of encountering phytotoxic levels indicated that up to 46.79 ha (115.7 ac) of surface soil are injured. This declined to 33% for alfalfa and herbaceous productivity and 29% for alder at 50 cm depth. A total of 17.12 ha (42.4 ac) of soil at these intermediate soil depths are injured. At depths of 100 to 150 cm, the probabilities declined further to 0 to 15%, corresponding to 7.30 ha (18.1 ac) of injured soil. Concentrations of some samples at 125 cm depth suggest >50% inhibition of plant growth.

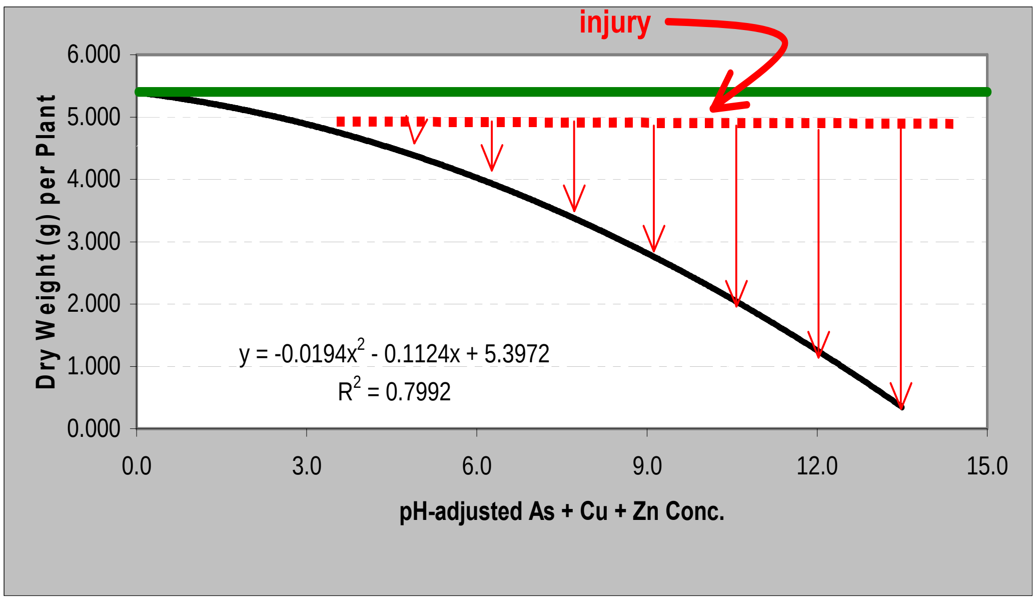

Figure 29. Conceptual depiction of Ph-adjusted As + Cu + Zn concentrations and injury defined as the $\geq$10% reduction in phytomass.

[The solid green line delineates growth at 100%; the dashed red line is set at 90% (i.e., 10% reduction in growth. As the pH-adjusted As + Cu + Zn level increases the severity of injury increases as shown by the widening gap between the dashed red line and the solid black line.]

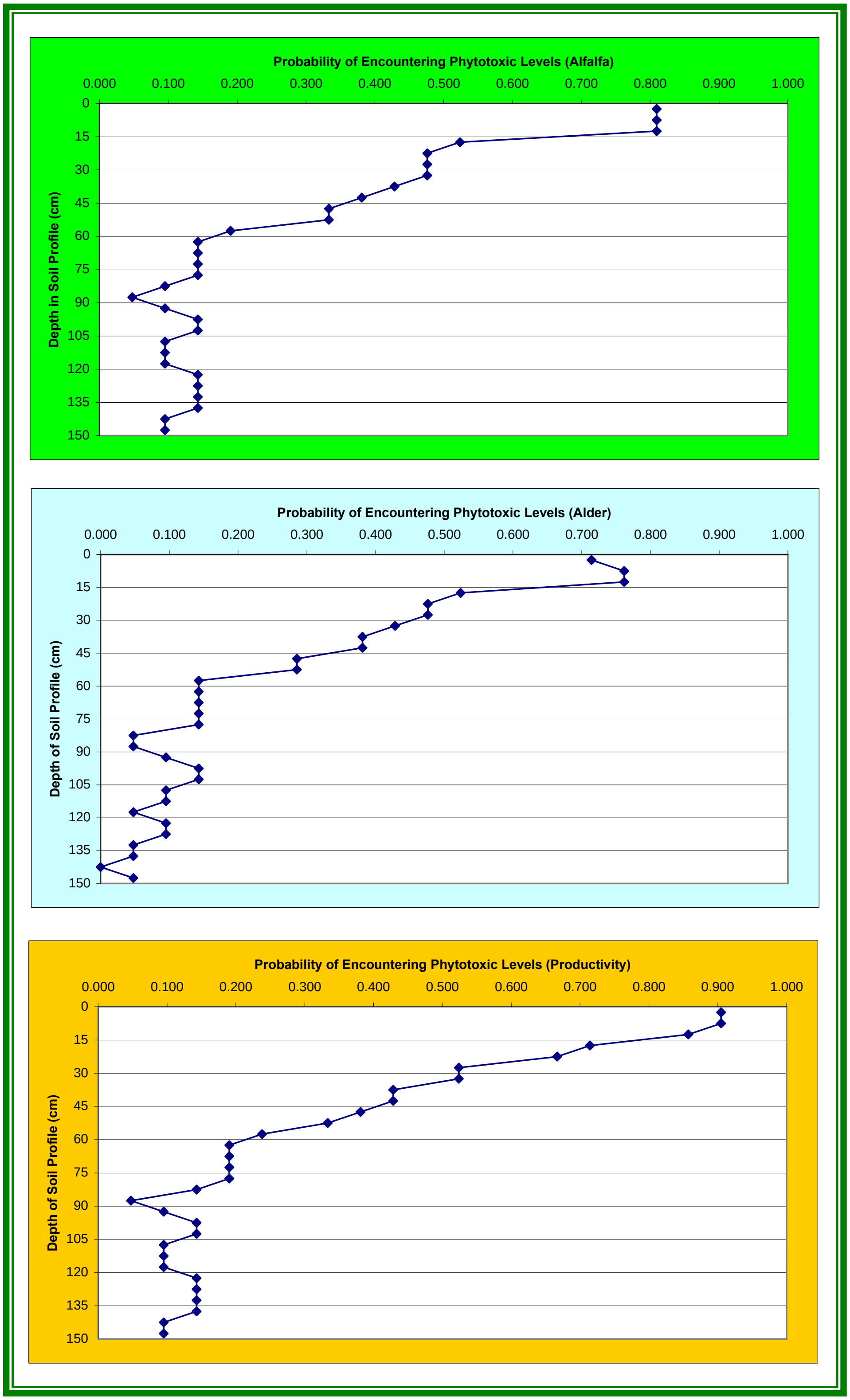

Figure 30. Probability of encountering phytotoxic levels of CoC at depth in the GRKO riparian area.

3.3.2.6 Microbial Process Measurements

Soil respiration is a legally defined measure of soil injury (43 C.F.R. § 11.62 (e)). Soil respiration is related to nutrient cycling processes important for plant growth, hence production [multiple citations of metal related effects on microbial processes are presented in Gannon and Rillig (2002)]. In soils with low or significantly altered soil communities, nutrients tend to accumulate in forms unavailable to the indigenous plants, and plant growth and productivity are severely compromised. Metal contamination is known to hamper the decomposition of litter and reduce soil respiration and microbial biomass. Several research groups have shown that the microbial community composition changes in response to mining associated metal contamination such as that existing in the riparian areas along the Clark Fork River. Several direct and indirect measurements of microbial activity and composition of microbial communities were taken on DOI lands in 2000 and 2001.

3.3.2.6.1 Materials and Methods

Multiple endpoints were measured to evaluate microbial functions. For more detail than presented in the summaries below, see Gannon and Rillig (2002).

Loss-on-Ignition estimates the amount of soil organic matter present in a sample.

Respiration (expressed as μmol CO_2 m^{-2} s^{-1}) was measured *in situ* using a LiCor 6400 photosynthesis instrument fitted with a Model 6400-09 soil respiration chamber.

Soil microbial biomass is a measure of the amount of carbon contained in the soil microbial biomass. The difference between paired fumigated and non-fumigated samples represents the amount of soil biomass.

Soil moisture was determined by gravimetric measurements.

Phospholipid Fatty Acid Analysis (PLFA) is a technique that has been widely used to characterize the microbial community structure in soils, including those contaminated with metals.

3.3.2.6.2 Findings

An ordination of the metal index against principal components (PC) 1 (41%) and 2 (16%) of the PLFA was developed. Sites were categorized according to degree of contamination. Sites were ranked according to a natural breakpoint that occurs in the metal index (a sum of CoC levels normalized in relation to baseline concentrations). The seven non-slickens sites that fell below the index number of 150 are considered to have low levels of contamination. Seven sites, with a metal index greater than 300, were highly toxic to microbes. Sites with intermediate index numbers were moderately toxic. Slickens sites containing un-vegetated ground were handled separately because microbial communities in un-vegetated soils can be expected to differ greatly from those in vegetated soils regardless of contamination.

Sites with low metal concentration and slickens sites are significantly different from each other and from all other groups along PC 1 (Figure 31). Sites with moderate and high levels of contamination are not significantly different from each other along PC 1, but do differ significantly along PC 2. Low CoC and slickens sites do not differ significantly from the other groups or each other with respect to PC 2.

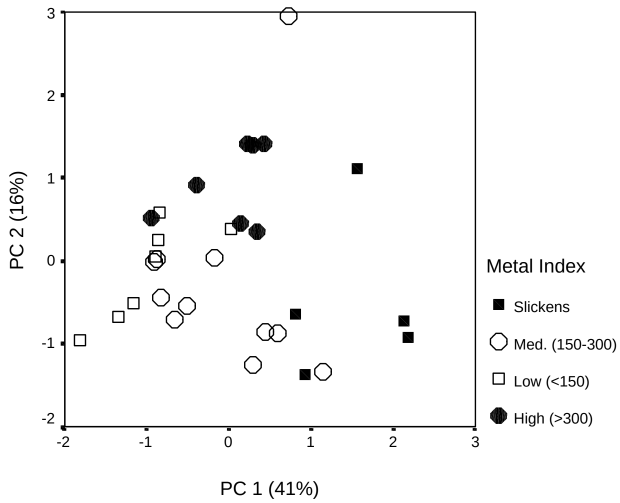

Figure 31. Results of principal component analysis of phospholipid fatty acid data.

Soil respiration values varied across sampling periods and among sample locations. Several controlling factors (e.g., temperature, moisture, organic matter, metals, and others) influence the rates of respiration. The confounding effects of other controlling factors was removed by plotting the maximum values achieved across different metal index levels (Figure 32). This maximum function is biologically meaningful: while at every metal concentration a number of environmental factors are acting upon respiration rates as measured in the field, the potential to achieve a high rate clearly decreases with increased metal index. With increasing metal concentration, metals have a more dominant effect with respect to respiration.

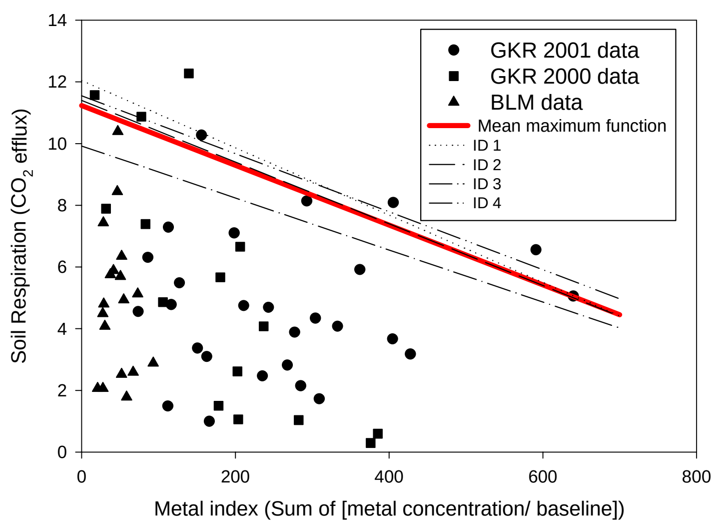

Figure 32. Scatterplot with average maximum function and the four different interval definition functions.

The percentage impairment of soil respiration due to metals (taken from the equation for the line in Figure 32) reaches biologically meaningful levels (inferred as $\geq$10% above the metal index of 100 (Table 16). The magnitude of impairment increases as CoC levels increase.

Table 16. Relationship between metal index and impairment of soil respiration.		
Metal Index Value	**Mean Respiration Rate ($\mu M\ CO_2 m^{-2} sec^{-1}$)**	**Percentage Impairment**
50	10.75	4.31
100	10.26	8.62
200	9.29	17.24
300	8.33	25.86
400	7.36	34.48
500	6.39	43.10
600	5.42	51.72
700	4.45	60.34

The metal loading index for microbial inhibition was used to predict the likelihood of encountering toxic levels at depth in the GRKO riparian soil profile. The index value of 100 corresponding to ~10% inhibition was used as the threshold. More than 75% of the uppermost layer of soil in the riparian area is injured in terms of microbial respiration (Figure 33). With depth, the likelihood of encountering toxic levels decreases such that at 37.5-cm depth, the likelihood of encountering toxic levels to microbes is 27%. Heterogeneous distribution of CoC is such that the likelihood of encountering toxic levels to microbes increases from 37.5 to 50 cm and again from approximately 70 to 90 cm.

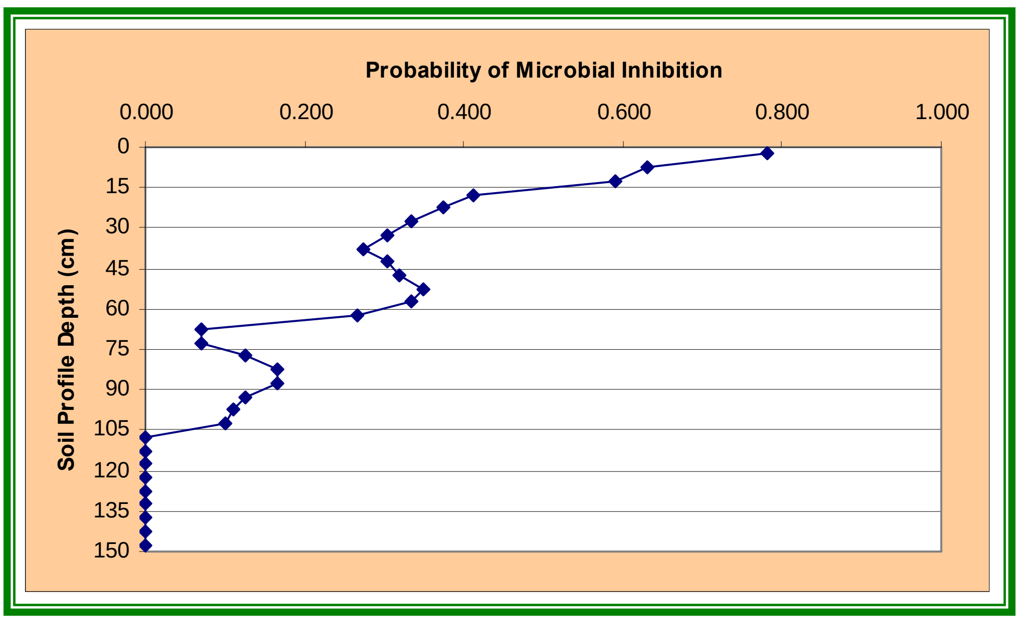

Figure 33. Probability of encountering toxic levels of CoC to microbes at depth in the GRKO riparian area.

3.3.3 Field Evidence of Injury

Areas within the riparian zone of the GRKO have surficial deposits of tailings. These are recognizable as areas devoid of vegetation, or essentially so. Fringes of surficial tailings are often comprised of swords of tufted hairgrass. The highest frequency of surficial tailings occurs in the southern portions of the property where the floodplain is broad.

3.3.3.1 Slickens

Surficial tailings devoid of vegetation and the margins supporting tufted hairgrass comprise 3.20 ha (7.9 ac) in the GRKO floodplain (Figure 34). Many smaller surficial tailings deposits (each ~1 to 2 m^2 area) were identified between July and September 2000. These were entered as points into ArcView (Figure 35). The multitude of small patches of surficial tailings underscore the high degree of heterogeneity of deposits on the GRKO. Aerial photographs from 1983, 1994, 1997, and 2001 indicate that barren areas expand or contract in relation to prevailing moisture conditions (See Moore *et al.*, 2001).

As moisture deficit conditions develop during the dry summer months, crystalline structures begin to form at the soil surface. These crystals vary in color from white, beige, orange, to various shades of bluish-green. These gypsum or gypsum-like crystals represent a concentrating process, whereby soluble, mobile constituents (including many of the CoC) accumulate at the soil surface during dry periods. Subsequently, during wet periods, the crystals dissolve and the CoC flow across the surface or back into the soil profile.

Across the floodplain of the GRKO, patches of dead or severely stunted vegetation occur. These localized areas may be associated with surficial tailings deposits, but also occur in areas having apparently non-contaminated or slightly contaminated surface soils. These areas are associated with buried tailings. The expression of toxicity in these areas is ephemeral in that exposure to toxic conditions is dependent on hydrodynamic processes and plant growth patterns. Effects have the greatest likelihood of being observed during periods of high moisture deficit, which occur in the mid to late portion of the growing season.

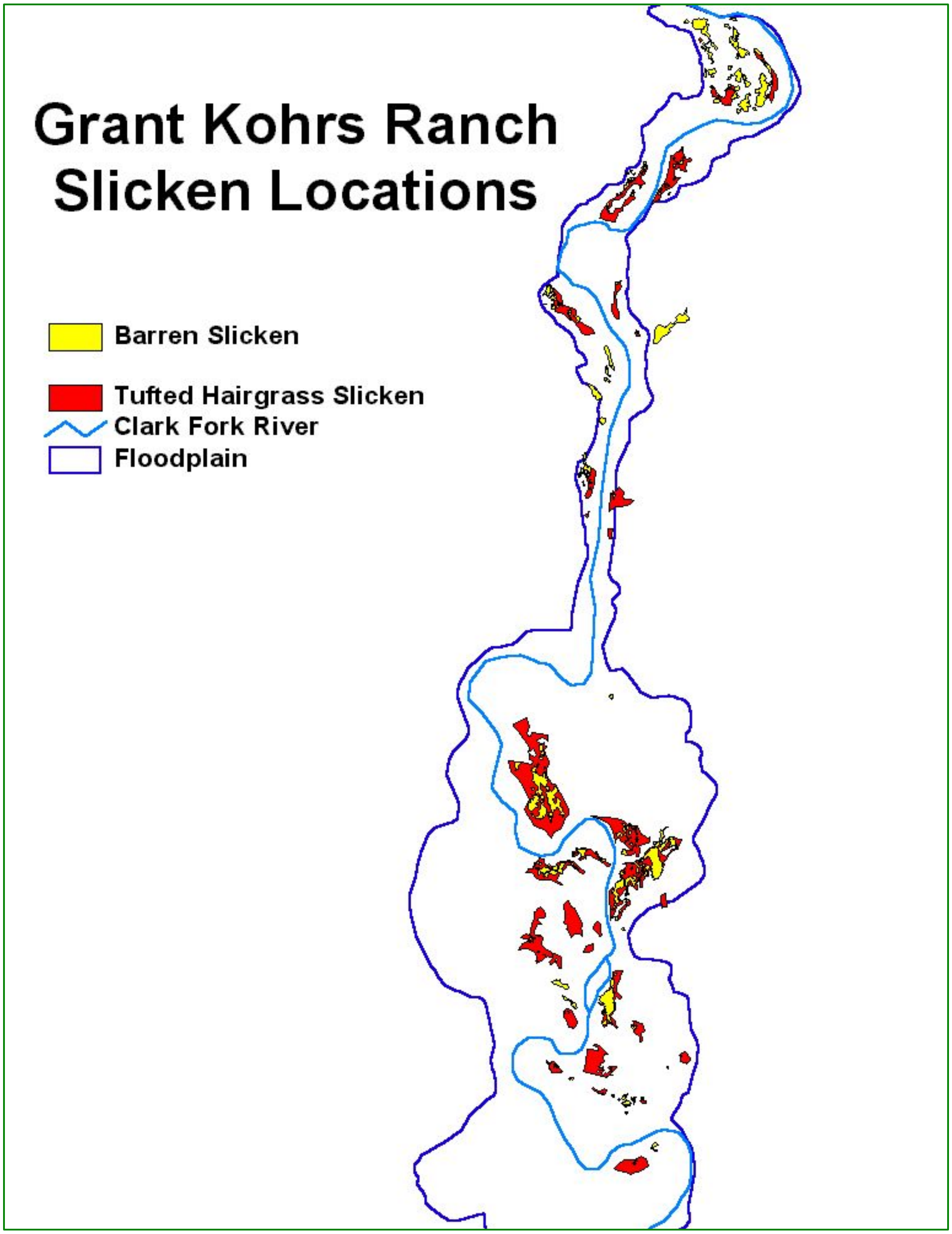

Figure 34. Location of barren slickens and slickens supporting tufted hairgrass on the GRKO.

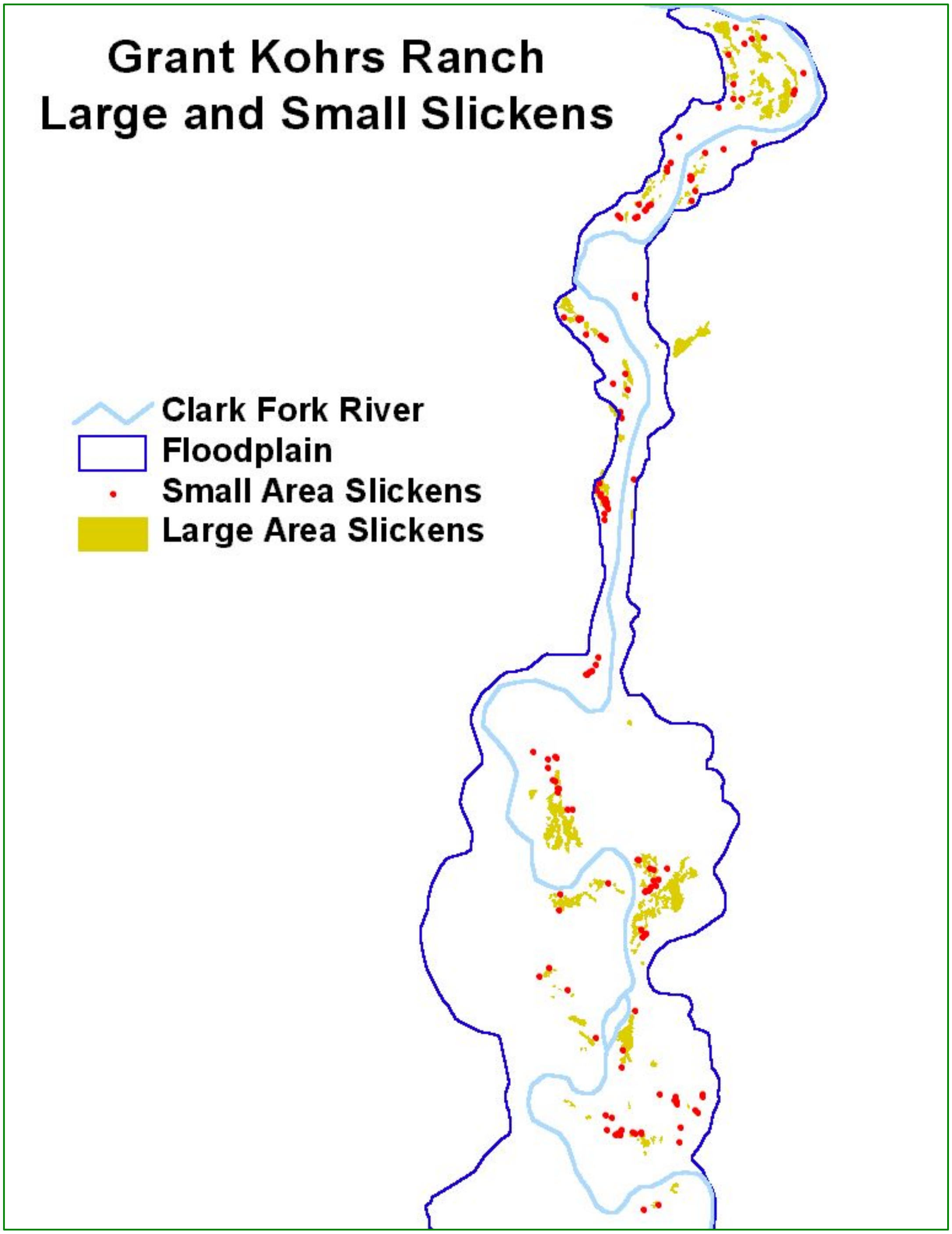

Figure 35. Point locations of small, barren slickens on the GRKO.

Quantifying changes over time in slickens size and extent is limited by image resolution, quality, and color of aerial photographs, especially of older photos such as that from 1947. Nevertheless changes in slickens areas and vegetation cover were obvious on the aerial photographs from 1947 to 2001. For the most part, the size and shape of the slickens remain the same from 1983 to 2001. However, the slickens were not static. Barren areas and areas of stressed vegetation appear to change over time. Perturbations, such as droughts and fires seem to have had a major effect on vegetation coverage and slickens extent. The amount of precipitation and discharge in the river (See Moore *et al*., 2001) indicated that there was much more water available for vegetation before and at the time the 1997 photographs were taken, compared to the other photographs. In the 1983 and 1994 pictures, there appeared to be a mix of flourishing and senescent/dead vegetation, and the slickens appeared to be the same basic size and shape. The 1997 aerial photographs exhibit larger shrub canopies, more grass coverage, and more vegetation coverage in general. The situation in 2001 reverted the patterns observed for the 1983 to 1994 period, that is to large areas of senescent/dead vegetation with slickens slightly larger. In 1997, (see Box A Figure IV-22 of Moore *et al*., 2001) shows the larger canopies and increased vegetation, especially at the riverbank and around the shrubs in the lower portion of the box, compared to the other years. Also, shrubs that appear to be flourishing in 1997 appear gray and leafless in the other photographs (see Box B and the west side of Box C of Moore *et al*., 2001).

Changes over time in response to a fire that burned an area in 1998 revealed slickens that were not evident in the earlier photos. The images show trends similar to other areas in that shrub canopies and vegetation seemed to increase dramatically from 1983 to 1997, then, in 2001, the barren areas increased. Fire seems to have exacerbated the dry conditions and, therefore, the number and sizes of slickens appear to have increased (Figure IV-24 of Moore *et al*., 2001). Comparisons show the changes from mixed healthy and senescent shrubs in 1983, to flourishing shrubs in 1997, to mostly senescent and dead shrubs in 2001 without the additional affects of fire (See Moore *et al*., 2001).

3.3.3.2 Streambank Stability

The GRKO contains 3.90 km (2.44 mi) of the Clark Fork River as measured along the mid-stream line from the southern to northern boundary. When the bank lines and side channels are included, stream length is 4.56 km (2.85 mi) within GRKO boundaries.[13]

The banks along the Clark Fork River within the GKRO usually consist of four stratigraphic layers or units (See Moore *et al*., 2001). The top layer (ca. 10 cm thick) is a sandy/silty, poorly consolidated soil, usually containing varying amounts of organic material and roots. The soil unit overlies a thicker layer (10 to 80 cm) of grayish-orange tailings composed of fine sand and silt. The tailings are usually lighter in color than the underlying units, and show orange and yellow mottling. Beneath the tailings lies a layer of grayish-brown silt/mud (20 to 50 cm) that is believed to be pre-mining floodplain deposits. A layer of sandy gravel and cobbles lies beneath the pre-mining floodplain deposits and is the lowest stratigraphic unit exposed in the banks. The thickness of the gravel/cobble unit is unknown, but is found throughout the study area. This stratigraphic package is prevalent throughout the riparian area and is seen in cores as well as bank exposures. The thickness of the various units is variable and any one unit may pinch out from one bank exposure to another.

The banks of the Clark Fork River within the Grant Kohrs Ranch National Historic Site were classified based on their morphology (See Moore *et al*., 2001). The basic classification consists of two main types of banks, concave and convex. The convex banks tend to be found in the straight reaches of the river and along the inside bends of meanders. Concave banks are found on the outside of meander bends and where riffles direct the flow into the banks.

Overall, the riverbank inventory included 9,200 m of banks, of which 3,145 m (34%) were concave "cutbanks" and the remaining 6,045 m (66%) were the more stable convex shapes. Both bank types

[13] These stream lengths exclude the area of scenic easement at GRKO's northern extreme.

are susceptible to undercutting and, therefore, a large portion of each type can be described as overhanging. Most of the erosion initiates in the lower gravel and mud layers, causing the upper layers (tailings, soil, and vegetation) to overhang the river. These overhanging banks occurred in 46% of the convex segments, with cuts typically 30 cm in depth at the base of the bank. Overhangs occurred in only 28% of the concave bank segments, but they also had a typical cut depth of about 30 cm. However, concave-bank undercuts usually occur in the middle portion of the bank and are not as clearly defined as those in convex banks. Most of the undercutting takes place in the gravels and old floodplain deposits, leaving the more resistant tailings layer overhanging and, eventually slumping into the river. Despite the higher percentage of overhangs, the convex segments possess slumps along only 5% of the banks, whereas slumps are present along 43% of the concave banks. There is a strong relationship between concave banks and slumping, which mostly occurs at riffles and meander bends where cutbanks are forming.

Tailings can be found in almost all of the banks exposed along the river. Where exposed in cutbanks or animal paths, the average tailings thickness is 37 cm, although these vary between 10 and 80 cm. The areas that lack tailings include a few short lengths where the channel has eroded into the edge of the meander belt and near the constructed sewage ponds at the north end of the park. Tailings thickness was measured rarely in the convex banks because tailings were generally not exposed. However, many of the bank segments exhibited evidence of tailings, such as adjacent slickens areas, salts forming on the lower banks, senescent/dead vegetation, and tufted hairgrass (an indicator species of high metals). Small exposures also were evident along animal paths. Visual estimates of vegetation on the bank face and woody vegetation within 2 meters of the bank were made. These indicated that convex banks were commonly more vegetated than the concave banks (84% vs. 39%, respectively), and had more woody vegetation within 2 m of the bank (32% vs. 20%, respectively).

Changes in channel position were quantified from digitized aerial photographs. Digitized bank lines were overlaid on the photos and the areas between the older bank lines and the 2001 bank lines were computed. Retreating banks occurred on the outside of meanders and on the advancing point bars on the inside. There were 435 m^2 of sediment eroded between 1983 and 1994 from the east bank in an area labeled “Northbend” (See Moore *et al.*, 2001). From 1994 - 1997, 623 m^2 were removed. And from 1997 to the present, the bank lost 102 m^2 of material. The large amounts of erosion in the first two time intervals seem to correspond to high flows in 1986 and 1997. The mean loss rate over all six locations is 0.5 meters/year. This rate is consistent with changes since 1947. The “Northbend” meander has migrated 40 meters since 1947. Again, it is important to note that the point bar is also advancing at similar rates, basically balancing erosion on the outside of the meander with deposition on the inside.

Erosion areas were digitized wherever there seemed to be significant distances (>1.1 m) between the older bank lines and the 2001 banks and where banks were obviously retreating from 1983 to 2001. The major control on bank erosion is the channel morphology. Specifically, major areas of erosion seem to occur where the shallow, turbulent riffles direct the water into the bank, and in outside of meander bends. The combination of riffles and bends that cause erosion are common. In river reaches where the channel is straight, with no riffles, there tends to be very little erosion.

The amount of land lost to channel migration between 1983 and 2001 was calculated by combining all of the areas of eroding banks. For example, “Northbend” has lost 0.117 ha (0.29 ac), “Stuart Field” has lost 0.097 ha (0.24 ac), and the bend just south of the park bridge ("Bridge South") has lost 0.089 ha (0.22 ac). The area eroded from the banks since 1983 has been 1.254 ha (3.1 ac). The area of erosion is approximately balanced by deposition in the point bars.

Bank stability does not appear to relate to vegetative cover. The penetration of roots to the erosion initiation point appears to be restricted by tailings. Most of the erosion initiates in the lower gravels and muds, which underlie the roots. The river erodes underneath them and the plants slump into the river with the rest of the bank sediment. The convex banks were more vegetated than the concave banks (see bank inventory section), however, this does not necessarily explain the stability of the convex banks. In fact, it may be the opposite: Convex banks support more plants because they are stable and concave banks cannot maintain vegetation because they are constantly eroding.

Thickness of tailings also does not seem to play a direct role in controlling bank erosion. Tailings are present along most of the river channel within the GRKO. Thickness does not seem to affect the occurrence or amount of erosion.

3.3.3.3 Plant Community Patterns

Canopy cover of all vascular plants was determined in 30 megaplots within the GRKO riparian zone during mid-summer 2001 (see Figure 19). Plot size and methodology correspond to the procedures used by Hansen *et al.* (1995) for characterizing riparian communities. For each plant species, Daubenmire cover class (T, P, 1, 2, …9,F) and mean height were recorded. Sampling was done from 25 July through 14 August 2001. Multivariate ordination techniques were used to show graphically and numerically the similarity in species composition between megaplots, and the correspondences of changes in community structure with changes in pH-adjusted metal loadings of the soil.

Megaplots with the highest pH-adjusted metals had similar species composition and differed as a group from megaplots with low and intermediate metal loadings. The changes in species composition were strongly correlated with changes in pH-adjusted metal loads of the soil. The pH-adjusted metal levels explained 63.5% of the variance in community structure and thus provides confirmation of the impact of metals on plant community composition. Canonical correspondence analysis provided confirmation of the impact of metals on community composition. The abundance of three species known to be metal tolerant was positively correlated with increasing pH-adjusted metal contamination of the soil Tufted hairgrass, redtop bentgrass, and Booth willow canopy cover increased as metal loading became more severe. Conversely, other species declined in abundance with increasing pH-adjusted metal contamination in the soil.

3.3.4 <u>Injury Quantification</u>

Injury quantification may be addressed either in terms of areal extent or in volume of the resource impacted. In this section, we have quantified both areal extent and volume, recognizing that volume may be the most important consideration[14] for the calculation of restoration options.

3.3.4.1 Areal Extent of Slickens

The perimeters of larger unvegetated tailings were recorded using a Trimble GPS unit and the circumscribed areas were calculated using ArcView. Unvegetated areas totaled 12,600 m^2 of the GRKO riparian area, including 7,570 m^2 of typical fine-grained slickens. Combined with slickens areas supporting tufted hairgrass, there are 3.20 ha (7.9 ac) of slickens (see Figure 34, Figure 35).

3.3.4.2 Areal Extent of Injured Soils not occurring as Slickens

Upward migration of CoC brings elevated levels of these hazardous materials to the surface, especially during dry periods (Smith *et al.*, 1998; Moore and Woessner 2001). Therefore, even areas that do not show evidence of injury to vegetation at a particular time are subject to injury under particular weather cycles from episodic migration of CoC from buried tailings; the long-term extent of injury must consider the occurrence of all buried tailings. The areal extent of buried tailings is substantially greater than that of slickens. No data have been generated so far to calculate this directly. However, the data produced to characterize soil profile distribution of CoC may be used to establish a density distribution plot, which would identify the likelihood of encountering buried tailings at any given location within the riparian area. Although this will quantify the proportion of the GRKO having buried tailings, it will not produce a georeferenced location. Consequently, there would not be a direct means of targeting a locale either for remediation or for restoration activities. Nevertheless,

[14] The tailings in the floodplain occur as surficial deposits and as buried deposits. Restoration may require some combination of amendments, mixing, or removal of highly contaminated zones. Costs of these restoration actions are related more to volume than to area.

this is an important site characteristic, which must be incorporated into the calculation of magnitude of injury.

3.3.4.3 Volume of Contaminated Soil

Calculations of the volume of contaminated soil used a threshold concentration of five-times baseline. Those values encompass potential variation within the baseline dataset and represent a conservative estimate of the presence of hazardous substances. Volumes of soils >5-times the baseline values were calculated as follows. An area of injured soil was determined both in the floodplain area[15] and in the historically irrigated fields. The area with soils concentrations elevated 5-times above baseline was determined using surface soil sample concentrations [upper 30 cm (12 in)]. An area encompassing all reasonably contiguous sampling sites with elevated concentrations was created as a theme in ArcView. Rather than contour the data, the boundary was chosen as 1/2 the distance between two sampling points where one was elevated and the other was less than 5 times the baseline unless a nearby major physiographic feature formed a natural boundary (see Figure 10 in Moore and Woessner, 2001). The upland and floodplain portions of the area were calculated (see Plates 12 through 16 in Moore and Woessner, 2001). The cumulative area of injured soil in the floodplain, defined as >5-times baseline concentration, ranged from 285,000 m^2 for Cd to 544,000 m^2 for Cu (Table 17). Substantial areas in the historically irrigated fields also exceeded the 5-times baseline concentrations, especially for Cu.

Table 17. Areas (m^2) of Soil with elevated CoC.		
CoC	**Fields**	**Floodplain**
As	308,000	532,000
Cd	90,700	285,000
Cu	2,860,500	544,000
Pb	354,000	544,000
Zn	1,840,000	544,000

Soil core and bank profile data (discussed above in 3.3.1.2 section Geologic Resources -- Riparian and Upland Soils, Findings, page 31) were evaluated to identify the median and maximum soil depths of elevated CoC concentrations (See Figure 11 in Moore and Woessner, 2001). The resulting values (Table 18) were multiplied by the respective areas of contaminated soil to calculate the volume of contaminated soil (Table 19). Within the floodplain, this reaches 520,000 m^3 for Cu and 540,000 m^3 for Zn.

Table 18. Depths (m) of soil with elevated CoC.				
CoC	**Floodplain**		**Fields**	
	Maximum	**Minimum**	**Maximum**	**Minimum**
As	0.95	0.15	0.40	0.20
Cd	0.75	0.15	0.40	0.18
Cu	0.95	0.25	0.40	0.06
Pb	0.95	0.15	0.40	0.15
Zn	1.00	0.25	0.40	0.05

15 The floodplain was delineated from interpretation of the geomorphology of the area [Moore and Woessner (2001)].

Table 19. Volumes (m³) of soil with elevated CoC.						
CoC	Floodplain		Fields		Total	
	Median	Maximum	Median	Maximum	Median	Maximum
As	80,000	510,000	62,000	120,000	140,000	630,000
Cd	43,000	210,000	16,000	36,000	59,000	250,000
Cu	140,000	520,000	160,000	1,100,000	290,000	1,700,000
Pb	76,000	480,000	53,000	140,000	140,000	660,000
Zn	140,000	540,000	92,000	740,000	230,000	13,080,000

3.3.4.4 Volume of Injured Soil

Soil injuries were demonstrated for the riparian area of the GRKO using biological endpoints; namely $\geq$10 depression of the endpoint for microbial respiration, alder growth, alfalfa growth, or productivity. Values from the respective regression equations were combined with the soil profile contamination plots (see Figure 30 for plant endpoints and Figure 33 for microbial endpoint). The proportional area of the floodplain exceeding the threshold injury concentrations was expressed as the area and the sum of soil at depth exceeding the injury threshold was expressed as the volume of injured soil (Table 20). Values vary slightly for the four endpoints used (microbial respiration, laboratory phytotoxicity with alder and alfalfa, and field measures of productivity) due to differences in the response functions.

Table 20. Area and soil volume of injured riparian area on the GRKO.				
Endpoint	Microbial Respiration	Alder growth	Alfalfa growth	Productivity
Area (ha)	42.57	41.45	44.04	49.22
(ac)	105.26	102.48	108.88	121.69
Volume (m^3)	8447	9,844	11,139	12,629
(yd^3)	11,049	12,876	14,570	16,518

The levels of CoC also were substantially elevated in the non-irrigated uplands from the air transport pathway. Historically irrigated fields and associated irrigation ditches have elevated CoC concentrations mainly as the result of carrying contaminated water and sediment and to a lesser extent, from aerial disposition of smelter emissions. Based on phytotoxicity and microbial investigations, these areas are not injured in terms of biological resources. However, the levels of contamination interfere with the National Park Service operating requirements of the GRKO under the National Park Organic Act of 1916, the enabling legislation (Grant-Kohrs Act, 1972), and compliance with other relevant environmental laws and regulations governing human exposures and proper handling of contaminated materials.

3.3.5 Ability of Resource to Recover

Phytotoxicity and reduction of microbial functions are severe on the most highly contaminated areas in the floodplain. These localities are most obviously associated with slickens, noted for the virtual elimination of plants (Smith *et al.*, 1998). Considering the geologic rate of change of slickens areas observed over time, such areas will continue to exist for centuries, absent active remediation.[16].

[16] Smith *et al.* (1998; p.17) state "The contaminated material in the bars is unlikely to be eroded for a long time (centuries) in the meandering reaches of a river …" Changes in the position of the river channel over the years cut off point bars, leaving slickens tailings buried by clean cover soil of varying depth. Persistence of

Seedling establishment will not occur successfully in such areas. Colonization of plants extending into highly contaminated areas by vegetative growth (e.g., root suckers, rhizomes, stolons) will succeed temporarily, but episodic die-back of such plants will occur; again the time frame is likely to be centuries.

Flood events influence recovery potential in three ways. First, deposition of clean sediment over contaminated layers provides a substrate that can support colonization and development of complex vegetation types. This has happened historically as evidenced by the prominence of buried tailings on the DOI lands. Second, deposition of contaminated soils from upstream deposits can layer new tailings deposits onto the floodplain. Such redistribution of tailings material has occurred historically, and until all upstream deposits are removed, will occur again. Whereas streambank stabilization efforts will help, a major flood may lead to repositioning of the channel and thus mobilize tailings. Third, scouring can remove clean deposits and expose buried tailings, thus creating anew slickens.

As evidenced on the GRKO, buried tailings episodically lead to injury. The prevailing climate of the region is characteristically one with moisture deficits. Upward movement of water through the soil profile carries CoC toward the surface where toxic responses occur. Active restoration management of emerging zones of plant stress will be required indefinitely to preserve the normal developmental characteristics of the riparian vegetation. The dynamic nature of the system makes it virtually impossible to predict with high accuracy, the precise physical location where new injuries will occur. Cumulative effects of multiple weather events over a season or multiple seasons may produce several years without noticeable injury; conversely, this may trigger a significant expression of injury to vegetation. The time frame for natural modulation of these phenomena is likely to be centuries.

Riparian vegetation, when intact and functioning properly, provides valuable ecological services. These include:

- critical habitat for fish, wildlife, and livestock providing both shade, cover, and food;
- active nutrient dynamics; and
- local retention of water through enhanced percolation and modulation of flood intensity.

Many plant taxa that inhabit riparian zones also occur in other habitat types, including wetlands, and play a role in water purification by their uptake of various toxics. When riparian vegetation is no longer able to stabilize riverbanks, runoff flows more rapidly in a shorter period, groundwater is depleted, and erosion increases, as does sedimentation downstream. Rivers are naturally dynamic, with alternate periods of high and low flows, erosion, channel migration, and deposition of sediments. In the case of the Clark Fork River, increased erosion and channel migration pose potential hazards as tailings deposits are exposed in unstable streambanks. Material eroded from the tailings will be redeposited elsewhere. Hence, maintaining the integrity of ecological processes and the natural riparian vegetation at GRKO is of primary importance not only to the Ranch, but also to the Clark Fork system as a whole.

The riparian plant communities along the Clark Fork River are especially important to the GRKO in terms of meeting the mandate for aesthetic, cultural, and educational opportunities. The GRKO requires a normally functioning riparian system to facilitate managed grazing, while offering floristic diversity, and aesthetically satisfying and historically significant vistas.

3.3.5.1 Plant Community Structure

Baseline conditions for natural plant communities of the GRKO consisted of the reference plot data on species composition and cover as described in Hansen *et al.* (1995) for the Montana Riparian and

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slickens and buried tailings with high CoC burdens will correspond to injuries to vegetation and to microbial communities for centuries.

Wetland Association (MRWA)[17]. Data were matched for each corresponding community type (Rice and Hardin, 2002). Though it is not possible to know which plant community might occupy a given locality, these reference data sets permit comparison of community composition and structure of like community types. In other words, one can compare whether the GRKO Community Type A' is similar to the MRWA (Hansen *et al*. 1995) prototype Community Type A.

Geographic data in the form of an aerial photograph and georeferenced shapefiles of ranch features were imported into ArcView. Polygons delineating discrete community types were drawn for the fenced riparian zone. There were 362 polygons delineated. Of these, 325 were comprised of 22 defined riparian community types; 20 that were designated as "Unclassified Riparian;" and 37 polygons were recognized as slickens (Table 21). Vegetation community types were determined following keys and definitions described for the state of Montana by Hansen *et al*. (1995). Mapping was conducted from 25 May to 20 June 2000.

Circular 50 m^2 plots were used to obtain vegetation data from 184 polygons following the standardized ocular plots macroplot method described in Hann and Jensen (1987). Data collected for each plant species included: Daubenmire cover class, height, distribution within the plot, phenology, and use by herbivores. For woody vegetation, additional data included size or age class (seedling, young, mature, decadent, dead) and shrub form (an indication of past use by browsing animals). Sampling was done between the dates of 29 June and 15 August 2000.

Sufficient quantitative data on plant community composition was obtain for 16 community types to permit statistical comparison with corresponding type communities from the MRWA. For 10 of the 16 plant community types, the GRKO species composition differed significantly from the MRWA reference standards (Table 22). These ten types account for 63% [32.5 ha (79.4 ac), including 3.2 ha (7.9 ac) of slickens] of the fenced riparian zone.

Thompson *et al.* (1995) mapped broadly defined vegetation communities and habitat types of the riparian area of the GRKO during the 1993 field season. Several of the riparian community types documented by Thompson *et al*. (1995) were categorized as human-induced disturbance types and are plant communities commonly associated with livestock disturbance in Montana. Thompson *et al*. (1995) ignored the possible influence of mining wastes as a factor related to vegetation composition. Further, the report implies that grazing pressure on the ranch was the primary factor controlling certain plant communities, lack of streambank stability, lack of tree/willow regeneration, and poorly functioning riparian attributes on the GRKO. A detailed re-assessment of the Thompson *et al.* (1995) study was performed in 2000 by Bedunah (2001). This showed that the methods developed by the Riparian Wetland Research Association (Hansen *et al*. 1995) to evaluate riparian and wetland conditions are not sensitive enough to classify a percentage of change associated with a type of disturbance (i.e. grazing or heavy metal) where both may be having an outwardly similar influence. Many of the dominant species comprising the disturbance communities are tolerant to elevated metal levels and increase with grazing (Table 23). These similar responses make it difficult to categorize these communities as associated with either livestock grazing or elevated levels of metals.

Rice (2002b) performed statistical analyses using ordination techniques [PC-ORD Version 4.15 (McCune and Mefford 1999)] to evaluate species composition of community types delineated in 2001 and of plant composition of megaplots (see Figure 19). These analyses demonstrated that species composition of plant communities on the GRKO not only differed from the MRWA reference communities, but also that shifts in species composition were related to metal loading (specifically the pH-adjusted As+ Cu +Zn level). Metal tolerant species increased in abundance on sites having high metal loading, whereas metal sensitive species decreased in abundance on sites having high metal loading.

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[17] The Montana Riparian/Wetland Research Program (RWRP) was previously the Montana Riparian and Wetland Association or MRWA; (RWRP, 2000). The acronyms are used synonymously in this injury assessment report.

Table 21. Community Types (number and area) on the Grant-Kohrs Ranch, 2000.					
Community Type	**Common Name**	**Polygons (N)**	**Area [ha**	**(ac)]**	**Percentage**
Seral Types					
BETOCC	Water birch	50	7.12	(17.6)	13.9
SALEXI	Sandbar willow	39	3.93	(9.7)	7.7
SYMOCC	Snowberry	18	1.34	(3.3)	2.6
PRUVIR	Chokecherry	1	0.12	(0.3)	0.2
	subtotals	108	12.51	(30.9)	24.5
Grazing Disclimax Types					
SALGEY	Geyer willow	70	11.45	(28.3)	22.4
BROINE	Smooth brome	18	6.88	(17.0)	13.5
JUNBAL	Baltic rush	20	2.26	(5.6)	4.4
AGRSTO	Redtop bentgrass	20	1.74	(4.3)	3.4
SALBEB	Bebb willow	9	0.81	(2.0)	1.6
POPTRI/SYMOCC	Cottonwood/snowberry	2	0.61	(1.5)	1.2
ROSWOO	Woods rose	10	0.49	(1.2)	1.0
POAPRA	Kentucky bluegrass	1	0.08	(0.2)	0.2
POPTRI/herbaceous	Cottonwood/herbaceous	1	0.08	(0.2)	0.2
SALLUT	Yellow willow	2	0.04	(0.1)	0.1
	subtotals	153	24.44	(60.4)	47.8
Climax Types					
SALGEY/CARROS	Geyer willow/beaked sedge	5	5.58	(13.8)	10.9
CARROS	Beaked sedge	12	1.34	(3.3)	2.6
CARLAS	Slender sedge	9	0.40	(1.0)	0.8
DESCES	Tufted hairgrass	8	0.24	(0.6)	0.5
TYPLAT	Cattail	4	0.20	(0.5)	0.4
CARAQU	Water sedge	2	0.20	(0.5)	0.4
ELEPAL	Spikesedge	3	0.04	(0.1)	0.1
SALDRU/CARROS	Drummond willow/beaked sedge	1	0.04	(0.1)	0.1
	subtotals	44	8.04	(19.9)	15.7
Other					
Slickens	Slickens	37	3.20	(7.9)	6.3
Unclassified riparian	Unclassified riparian	20	2.91	(7.2)	5.7
	subtotals	57	6.11	(15.1)	12.0
	TOTALS	**362**	**51.10**	**(126.3)**	**100.0**

Table 22. Community composition of 16 community types compared to MRWA reference standards.

Community Type	Common Name	Statistical Difference (*p*<0.05)
Seral Types		
BETOCC	Water birch	Statistically Different than Reference
SALEXI	Sandbar willow	Statistically Different than Reference
SYMOCC	Snowberry	Statistically Different than Reference
PRUVIR	Chokecherry	Insufficient data to test
Grazing Disclimax Types		
SALGEY	Geyer willow	Statistically Different than Reference
BROINE	Smooth brome	Insufficient data to test
JUNBAL	Baltic rush	Not Different than Reference
AGRSTO	Redtop bentgrass	Insufficient data to test
SALBEB	Bebb willow	Statistically Different than Reference
POPTRI/SYMOCC	Cottonwood/snowberry	Not Different than Reference
SALLUT	Yellow willow	Not Different than Reference
ROSWOO	Woods rose	Not Different than Reference
POAPRA	Kentucky bluegrass	Insufficient data to test
POPTRI/herbaceous	Cottonwood/herbaceous	Insufficient data to test
Climax		
SALGEY/CARROS	Geyer willow/beaked sedge	Statistically Different than Reference
CARROS	Beaked sedge	Statistically Different than Reference
CARLAS	Slender sedge	Statistically Different than Reference
DESCES	Tufted hairgrass	Statistically Different than Reference
TYPLAT	Cattail	Not Different than Reference
CARAQU	Water sedge	Not Different than Reference
ELEPAL	Spikesedge	Statistically Different than Reference
SALDRU/CARROS	Drummond willow/beaked sedge	Insufficient data to test
Other		
Slickens	Slickens	Not Applicable
Unclassified riparian	Unclassified riparian	Not Applicable

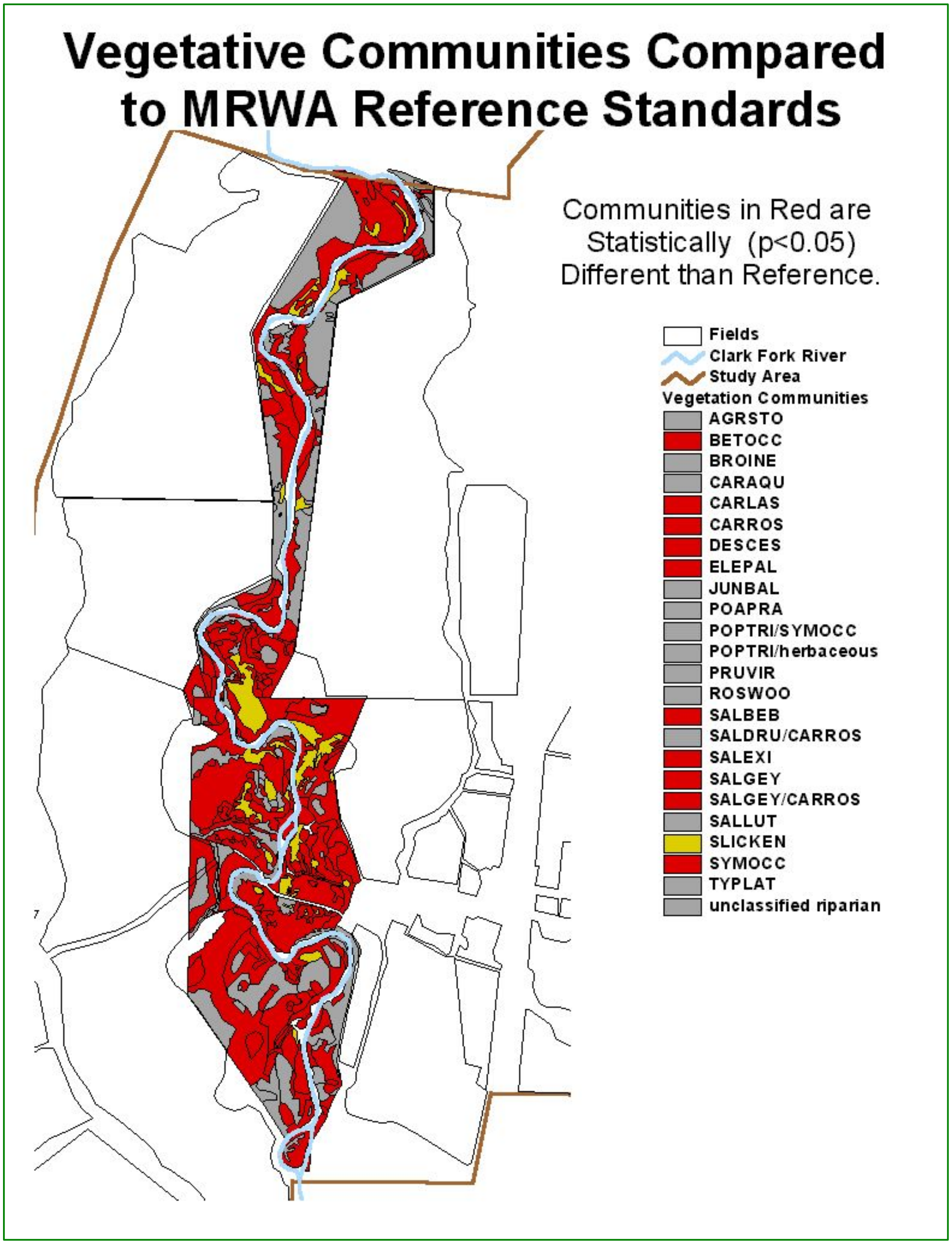

Figure 36. Distribution of plant communities deviating from MWRA reference type.

There is little doubt that human disturbance, livestock grazing, sedimentation, and stream changes associated with mining in the Upper Clark Fork River watershed, have impacted riparian communities and function. As the majority of the disturbance-adapted plants that dominate the ranch's riparian areas are both grazing resistant and metal-tolerant, it is difficult to assign a causative factor or a percentage of change associated with a causative factor.

Table 23. Grazing response, metal tolerance, and origin for some important species found on the Grant-Kohrs Ranch National Historic Site.

Species	Grazing Response	Metal Tolerance	Origin
Graminoids			
Agrostis stolonifera	Exotic, Aggressive	Tolerant[1]	Introduced
Agropyron repens	Exotic, Aggressive	Unknown	Introduced
Bromus inermis	Exotic, Aggressive	Unknown	Introduced
Carex rostrata	Decreaser	Tolerant[8]	Native
Deschampsia cespitosa	Decreaser	Tolerant[2, 10]	Native
Juncus balticus	Increaser	Tolerant[7, 9]	Native
Poa pratensis	Exotic, Aggressive	Unknown	Introduced
Forbs			
*Centaurea maculosa**	Exotic, Aggressive	Tolerant[5, 7, 8]	Introduced
*Cirsium arvense**	Exotic, Aggressive	Tolerant[5, 7, 8]	Introduced
*Euphorbia esula**	Exotic, Aggressive	Tolerant[5, 10]	Introduced
Glycyrrhiza lepidota	Increaser	Tolerant[9, 10]	Introduced
Trifolium hybridum	Exotic	Unknown	Native
Shrubs			
Betula occidentalis	Decreaser	Tolerant[3, 4, 9]	Native
Rosa woodsii	Increaser	Tolerant[5, 6, 7, 9]	Native
Salix boothii	Decreaser	Tolerant[3]	Native
Salix bebbiana	Decreaser	Tolerant[11]	Native
Salix exigua	Decreaser	Tolerant[3]	Native
Symphoricarpus occidentalis	Increaser	Tolerant[9]	Native
Trees			
Populus trichocarpa	Decreaser	Unknown	Native

* Species on Montana Noxious Weed list.
[1] Rauser and Winterhalder (1985), Wu, Bradshaw, and Thurman, (1975), and Wu and Antonovics (1975).
[2] Cox and Hutchinson (1980), Hertstein and Jager (1986), Rauser and Winterhalder (1985), Von Frenckell-insam and Hutchinson (1993).
[3] Massey, J. G. 1998.
[4] Brown, M. T., and Wilkins, D. A. 1985.
[5] Referenced by Dr. Tom Keck, Natural Resource Conservation Service, Deer Lodge Montana (personal communication; memo from S. Jennings to B. Rennick, June 5, 1998; Keck *et al*., Mapping Soil Impact Classes on Smelter Affected Lands).
[6] Personal communication with Dr. Frank Munshower, Montana State University, Bozeman.
[7] Field observations by Bob Rennick, CDM Federal Program, Corporation, Helena, Montana.
[8] Reconnaissance conducted by the Reclamation Research Unit, ARTS Phase I Final Report, 1993.
[9] Field observations by Janet Hardin, Botanist, The University of Montana, 2000.
[10] Riparian and Wetland Research Program addendum to the Clark Fork River Riparian Zone Inventory. 1998.
[11] Ray, G. J. 1985.

The Thompson *et al*. (1995) statements that the plant communities and problems associated with polygon condition are associated with livestock grazing were speculative and not supported by evidence. Additionally, Thompson *et al*. (1995) listing of the *Deschampsia cespitosa* habitat type as a non-disturbance type on the GRKO does not account for the strong evidence that the metal tolerant graminoid *Deschampsia cespitosa* is related to tailings deposits in the Upper Clark Fork River Valley

(Rice and Ray 1984, Massey, 1998; Rice, 2002b). The pace of recovery expected after seven years of cattle exclusion from the riparian zone suggests strongly that CoC are suppressing the rate at which the ecological system is able to recover from stress, in this case cattle grazing.

3.4 Weight-of-Evidence Analysis

The overall study design employed in the collection of the 2000 and 2001 investigations that form the primary basis for this determination of injury focused on a concept referred to as a soil triad (Figure 37). This concept examines consistency of data in complex systems, in which environmental concentrations of hazardous substances are related to laboratory toxicity effects and field observations of communities.

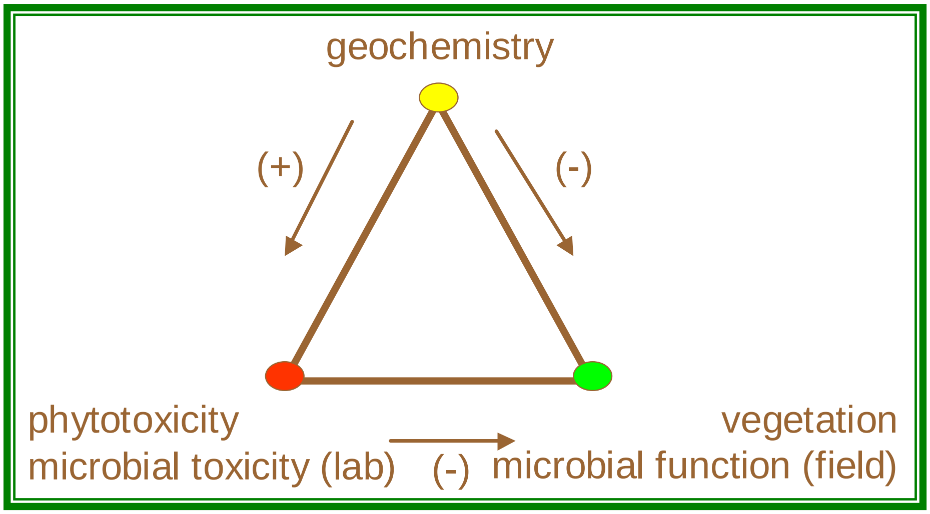

Figure 37. The *Soil Triad* relating environmental CoC concentration, laboratory toxicity tests, and field observations.

Qualitative and quantitative logic tests have been used in weight-of-evidence analyses to establish linkage between environmental parameters and biological responses (Hill, 1965; Menzie *et al*., 1996). Multiple lines of evidence are considered.

- Strength .... Is the magnitude of the effect associated with exposure to the stressor high?
- Consistency .... Does the same effect-response occur repeatedly?
- Specificity .... Is the effect diagnostic to the stressor?
- Temporality .... Does exposure precede effect?
- Gradient .... Does a positive correlation between stressor and effect exist?
- Plausibility .... Do mechanisms-of-action and exposure-routes exist that could result in the observed effects?
- Coherence .... Are the hypotheses tested relative to the stressor effects consistent with ecological and toxicological knowledge?
- Experimental Evidence .. Did the data analysis confirm or reject the null hypotheses?
- Analogy .... Do similar stressors cause similar responses?

Each injury endpoint in the investigations of the DOI was evaluated against these criteria for the question "Are the observed effects related to the presence of hazardous substances?" Collectively this analysis conclusively establishes injury due to past and continuing releases of CoC from mining activities (Table 24).

The literature on toxicity summarized previously and the data compiled in the several studies of the area firmly establish that the CoC are strongly linked to the observed effects. Of the criteria, specificity was ranked as moderate or weakly linked to the endpoint response due to the fact that other stressors can evoke similar effects in plants or microbes, especially at the community level. Experimental evidence was ranked as moderate for microbial toxicity and community level effects, due to systematic "noise" in the data from other potential stressors. Nevertheless, the overall strength of the relationships is very strong.

Table 24. Weight-of-evidence assessment of injury endpoints for riparian areas.

Injury Endpoint	Phytotoxicity	Productivity	Plant Community Structure	Microbial Respiration	Microbial Community Structure
Strength	+++	+++	++	+++	++
Consistency	+++	+++	++	+++	++
Specificity	++	++	+	++	+
Temporality	+++	+++	+++	+++	+++
Gradient	+++	+++	++	+++	++
Plausibility	+++	+++	+++	+++	+++
Coherence	+++	+++	+++	+++	+++
Experimental Evidence	+++	+++	++	++	++
Analogy	+++	+++	+++	+++	+++

3.5 CONCLUSIONS

Hazardous substances from large-scale mining operations have contaminated the soils of the GRKO. The levels of contamination are greatest in the floodplain roughly corresponding to the riparian zone. Continuing releases of hazardous substances are occurring as CoC are mobilized by groundwater percolating and wicking through the soils. Erosion of streambanks also provides a continual source of newly exposed tailings.

The levels of contamination are well above background concentrations. Moreover, the levels were shown to be sufficiently high to cause phytotoxic responses in several species including close relatives of plants inhabiting the area. Soil respiration, primarily a measure of microbial activity exhibited patterns of inhibition similar to the phytotoxic responses. Field measurements of primary productivity showed close correspondence with laboratory measures of phytotoxicity. In addition, the composition of plant communities were shown to be sub-nominal based on comparisons to riparian reference type communities. Distribution and abundance of plant species shifted in relation to metal loading across the riparian zone. This was most evident as known metal tolerant species increased with increasing metal loading, whereas metal intolerant species decreased with increasing metal loading.

Individually, and collectively, these effects diminish the aesthetic character of the landscape and prevent the Department of the Interior from fully achieving its Congressional mandate. The cultural landscape has been contaminated with hazardous substances released from mining, ore processing, and smelting operations in Butte and Anaconda, Montana, which occurred at a large scale from the 1880s until the early 1980s. In relation to the services expected of the natural resources of the GRKO, the contamination has caused:

1. A significant alteration in the vegetative composition of the riparian corridor;
2. The loss of land due to tailings-related stream bank instability;
3. Reduced productivity in natural and agricultural vegetative growth;
4. Increased ecological vulnerability to drought, fire, disease, and infestation;
5. The invasion of the riparian area and the lower meadows by exotic plant species;
6. Limitations in the use of the riparian area for ranch operations, interpretation, education, and public enjoyment;
7. Reduction in grazing area available for livestock;
8. Degradation of terrestrial wildlife habitat;
9. Degradation of soil quality in historically irrigated fields and non-irrigated uplands;
10. Increased operational costs for ranch management; and
11. Reduced visitor enjoyment.

Therefore, the human and ecological services provided by the cultural landscape have been injured due to the negative impact hazardous substances have had, and continue to have, on the natural processes necessary to maintain the nationally significant characteristics of the landscape. The landscape provides a diminished set of human and ecological services and cannot be managed, as would be the case in the absence of mining-related hazardous substances.

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APPENDIX A. ANNOTATION OF PRIOR STUDIES

Chronological Listing and Abstracts of Site-Specific Studies

Grant-Kohrs Ranch NHS and Bureau of Land Management Parcels

Clark Fork River Operable Unit

1. Rice, Peter M. and Gary J. Ray. *Flora and Faunal Survey* & *Toxic Metal Contamination Study of the Grant-Kohrs Ranch National Historic* Site. Gordon Environmental Studies Laboratory, Botany Dept. University of Montana, Missoula, MT: May 1984 (76 pp).

- Broadly distributed report. Cited in the RI, ERA, and HHRA.
- AA spectrophotometry analysis of 0-25 cm soil samples for Cu, As, and Cd.

GRKO Riparian Zone	Study Control Area (Blackfoot River)
Average Cu = 1630 ppm	13 ppm
Average As = 176 ppm	4 ppm
Average Cd = 5.0 ppm	< 0.1 ppm

- Meadows and hayfields significantly elevated in Cu, As, and Cd.
- Sampling and vegetation analysis limited to the 216 acre area of uplands and riparian corridor that made up the NPS ownership at the time of the study.
- Metal concentrations in vegetation: redtop bentgrass 10.4 ppm Cu, 1.4 ppm As, 0.12 ppm Cd [> twice check plot values (i.e., Tin Cup Joe Creek)].
- Identified 0.2 hectares of slickens where 'soil microbe enzyme activity is depressed by 85% of normal.'
- Acute toxicity to vegetation is evident in the slickens, no apparent risk of acute livestock toxicity exists.
- Suggested action levels for the ranch:

Metal	Material	Receptor	Caution Level (ppm)	% of 216 acre Ranch exceeding level
Copper	Soil	Vegetation	400	52
	Foliage	Vegetation	15	11
	Forage	Animals	15	11
Arsenic	Soil	Vegetation	200	36
	Foliage	Vegetation	2	15
	Forage	Animals	2	15
Cadmium	Soil	Vegetation	5	22
	Foliage	Vegetation	Not specified	
	Forage	Animals	0.4	1

- Sampled floodplain soils up and downstream of GRKO (average ppm shown below):

Site	No. of Samples	Copper	Arsenic	Cadmium
Rocker	3	1102	164	10.0
Racetrack	8	2375	402	11.6
Garrison	8	1567	629	5.0
Drummond	7	4155	578	12.9
Tin Cup Joe Creek	3	53	26	1.7
Blackfoot River	1	13	4	<0.03

2. Ray, Gary J. *Baseline Plant Inventory of the* Grant-Kohrs *Ranch.* Gordon Environmental Studies Laboratory, Botany Dept. University of Montana, Missoula, MT: July 1984 (14 pp).

- Supplementary to the Floral & Faunal Survey & Toxic Metal Contamination Study...
- Provides a summary of a baseline vascular plant inventory conducted at GRI<O in 1983, which was limited to the original 216 acre NPS ranch site.
- Discusses 'quasi-prairie remnants' near visitor center and an 11 hectare tract within the scenic easement as areas to be preserved
- Highlights wetland habitat rich in wildlife, particularly the west side slough.
- The report narrative is only 4 pages.

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3. Rice, Peter M. and Ray, Gary J. Heavy *Metals in Flood Plain* Deposits *Along the Upper Clark Fork River.* Gordon Environmental Studies Laboratory, University of Montana, Missoula, MT in *Proceedings: Clark Fork Symposium,* Montana Academy of Sciences, April 19, 1985 (45 pp).

- Used in proceedings of the Clark Fork River Symposium, Montana Academy of Sciences. May not have been written specifically for Grant-Kohrs, but is now part of EPA Administrative Record.

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4. Ray, Gary J. *Effects of Heavy Metal Enrichments on a Riparian Plant Community in the Upper Clark Fork River Basin.* Master of Arts Thesis, University of Montana, Missoula, MT: December 1985 (103 PP).

- Direct gradient analysis to determine metals effects on the distribution of riparian plants.
- 'Soil pH affects plant distribution indirectly by controlling metal solubility.'
- '...depression of plant community coverage and species richness along transects corresponds closely with the solubilities of copper and cadmium. Evidence of similar changes in zinc solubility along the coenocline indicates that it, too, may augment overall phytotoxicity.'
- 'Species in the community are apparently dispersed according to differential metal tolerances.'
- Used strip-transects across gradients identified by composition in vegetation.
- Includes a literature review of phytotoxicity and its measurement (e.g., root elongation) for Cu, Cd, and As.
- Collected 120 soil samples at 0-2.5 cm, 0-25 cm *[sic],* and 25-75 cm.
- Collected 49 plant tissue samples of redtop bentgrass and Bebb's willow.
- Metals concentrations in study slicken were more than 2 orders of magnitude greater than that *of* the check and control stations.
- 'Total concentrations of any of these elements are not appreciably higher in the clearing [i.e., slickens deposit] than in the surrounding soils.' (p 43)

Mean total concentrations of heavy metals in the top 25 cm of soil (ppm) — p 44

Element	Study Site	Check Site*	Control Site^
Cu	2170	53	13
As	492	21	4.1
Cd	5.9	1.7	0.03

* Tin Cup Joe Creek
^ Blackfoot River

- 'Heavy metal residues are irregularly assorted in the upper 75 cm of soil, except in the top 2.5 cm. Higher concentrations of copper and cadmium have accumulated at or near the soil surface.' (p 45)
- Microbial enzyme activity: 'A severe reduction (about 88%) in enzymatic activity was reported for non-vegetated sites, while vegetated sites exhibited normal levels...A check plot at Tin Cup Joe Creek manifested only a slight depression (about 7%) of microbial activity.' (p 71)
- 'A decline in community cover corresponded strongly with an increase in the solubility of copper and cadmium in the top 25 cm of soil.' (p 80)
- 'D. cespitosa clearly exhibits a higher tolerance for the more acidic sites, dominating vegetated sites where soil pH is between 4.2 and 4.4.' (p 94)
- 'Phosphorous deficiency, frequently problematic on mine spoils, is not evident. Levels of K, Ca, and Mg are normal to abundant.' (p 96)
- 'The gradient analysis suggests that distributional relationships among species are affected primarily by changing solubilities (shifting toxicities) along the transects...Toxic conditions in the substrate are severe enough to extirpate the entire plant community in certain areas, and in other areas all but one or two species are depressed. The community as a whole, rather than competing for limited resources, is apparently being sorted out according to the differential metal tolerances of resident species populations forced to cope with metal toxicity.' (p 96)

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5. Foster, Dan. *Grazing in the Clark Fork River Riparian* Zone, Memorandum to Files, Grant-Kohrs Ranch NHS, Deer Lodge, MT: May 27, 1994 (1 pp).

- 'There will be no grazing in the riparian zone of the Clark Fork River. We are doing this because of the concern of potential uptake of heavy metals.'

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6. Rader, Brian R. *Toxicological Evaluation of 'Slicken'* Areas *in the Flood Plain Deposits Along the Clark Fork River,* Grant-Kohrs *National Historic Site, Deer Lodge, Montana: Study Plan.* Colorado State University, Fort Collins, CO: July 14, 1994 (21 pp).

- Contains a detailed background about mining history in Butte and Anaconda.
- Study plan and background information for Radar's Masters thesis.
- Proposed investigating slickens toxicity using single species bioassay tests (germination tests, trout survival tests, and earthworm behavior/avoidance test) and comparing this to indicator species in the floodplain.

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7. USDOI Bureau of Land Management. *X-Ray Fluorescence Sampling and Analysis Report,* GrantKohrs Ranch NHS, Deer Lodge, MT #1703 (SC-212B) CONFIDENTIAL USDOI, BLM Service Center, Denver, CO: 1994/5 (7) (115 pp).

- This is a screening level study discussed in the Human Health Risk Assessment and ERA.
- The report contains data sheets and methodological information for 757 surface soil samples performed in October 1994.
- Contains Appendices A-D, grid map of 1994 sampling, and a letter from Tom Ulrich to Karl Ford dated 01/12/95, describing sampling method and clarifications of data set (10 pp).
- October 10-20, 1994: Karl Ford, 757 soil sampling points on grid across GRKO
  Determine the nature and extent of contamination using a portable X-Ray Fluorescence device.
  Considered Level III quality data ('quantitative' = percent bias <1251% compared to lab results).
- Sites not GPSed — no unit available at time of sampling. NPS staff walked and sampled along transects using compass bearing.

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8. Meyer, Paul, Karl Ford, Robert Bump, and Peter Bierbach. *Preliminary Characterization of Soil Metals Concentrations on BLM Lands, Clark Fork River; Montana.* Bureau of Land Management, National Applied Resource Science Center, Denver, CO; BLM Missoula and Billings Offices: August 18, 1995 (55 pp).

- XRF study of soils on 11 of 15 BLM tracts along the CFR; 118, 0-3" samples collected October 25-28, 1994.
- BLM manages 15 tracts, 2,409 acres, along the Clark Fork River (p 3).
- Considered a reconnaissance effort, sampling on 11 of 15 tracts.
- Data quality objective of Level III (quantitative) was achieved.
- No visible slickens areas were reported (p 5).
- 'It appears that arsenic and lead are not contaminants of concern.' (p 6)
- 'All tracts showed mean concentrations elevated above baseline...for copper and zinc, and most did for arsenic. For copper and zinc, tracts 1, 3, 4, 5, 9, and 12 have the greatest proportions of samples with concentrations more than 10x that of baseline.' (p 7)

Element	Reference Concentrations		No. of BLM samples > 10x
	Kabala-Pendias & Pendias, 1992*	Deere et al, 1995[A]	
Copper	27	34.2	83
Zinc	65	102.2	34
Arsenic	7	27.8	4
Lead	20	35.9	1

* Median soil concentrations (ppm) in Western United States soils
Baseline concentrations for riparian soils in two control streams in the Clark Fork River Basin

'Several samples from tracts 4 and 5 also had copper concentrations that exceeded baseline by more than 100x. These high levels probably are explained by isolation of these sample sites by oxbows, depositional areas now cut off from the main channel, and from perennial washing, scouring, and remixing with other materials following original deposition. The oxbows on tract 4 and 5 formed following construction of the railroad right-of-way between 1924 and 1930, after tailings releases from sources upstream.' (p 8)

Mean XRF values (•pm)				
Tract #	Copper	Zinc	Arsenic	Lead
1	1022	1217	103	107
2	251	1069	30	91
3	522	803	42	51
4	1076	736	59	82
5	1184	455	56	131
7	554	630	50	21
8	275	883	46	113
9	468	1199	36	89
12	571	1139	67	51
13	225	543	37	44
15	353	727	32	11

- Ranges of soil metals levels (ppm) having phytotoxicity effects on crops (Kabata-Pendias, 1992)
  - Arsenic .... 15 - 50
  - Copper .... 60 - 125
  - Lead .... 100 - 400
  - Zinc .... 70 - 400

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9. Rader, Brian R. A *Toxicological Evaluation of Contaminated Floodplain.* Soils *along the Clark Fork River, Grant-Kohrs National Historic Site, Deer Lodge, Montana.* Thesis, Master of Science, Colorado State University: Fall 1995 (107 pp).

- Published Master's thesis.
- Purpose: (1) determine toxicity of slickens soils to germinating seedlings and to earthworms, (2), compare the sensitivities of indicator species used in this study, and (3) attempt to estimate the influence of pH and trace metals on the phytotoxicity of contaminated floodplain soils within GRKO.
- 'Earthworms, *Eisenia* foetida *andrei,* placed in 100% slicken soil twitched violently when they contacted the hydrated slicken soil surface and died within two hours. LC_{50} values for earthworm survival depended on diluent selection, with the sand dilution resulting in the smallest LC50 (LC_{50}=3.0% slicken soil) and the limed artificial soil dilution resulting in the largest LC50 (LC_{50}=46.5% slicken soil). In the avoidance behavior testing, avoidance of the contaminated slicken soil was a much more sensitive indicator of slicken contamination than acute lethality. Using the limed artificial soil dilution series (LC_{50}=46.5% slicken soil), earthworms displayed significant avoidance of the most dilute sample tested, the 3.13% slicken soil dilution. Threshold avoidance was below 3.13% slicken soil.' (p iv-v)
- 'The most sensitive endpoint in the seed germination tests was root length. Emergence was the least sensitive endpoint.' (p v)
- '...the slickens generally did not have higher levels of total metals than did the vegetated reference sites with which they were paired.' (p v)
- '...we found- that the soils collected from slicken sites were more acidic than the soils collected from reference sites, indicating that pH may be controlling the biologically available fraction, hence the toxicity, of metals in these soils.' (p vi)
- 'Results of germination tests performed on pH manipulated soils showed that...both low pH and the presence of elevated concentrations of metals were necessary to cause the phytotoxic response.' (p vi)
- 'Schafer and Associates and MSU (1993), summarizing results of the Silver Bow Creek Streamside Tailings and Revegetation Studies (STARS) Project, noted no significant differences in total metal concentrations between amended tailings treatments...and undisturbed tailings, though the amendments reduced the mobility and toxicity of metals in floodplain soils. The authors also stated that revegetation of amended tailings reduced migration of metals in surface runoff and as eroded sediment, and reduced the risk of contaminate *[sic]* migration into groundwater.' (p 16-17)
- Performed germination tests on lettuce, radish, barnyard grass, and redtop bentgrass.
- August 1993, Reconnaissance Study, took 11 point samples along a continuous transect across 2 slickens on both sides of the Clark Fork River.
- July 1994, Detailed Study, performed dilution series and a 7.62 m transect (6 soil samples) of one of the 1993 slickens.
- July 1994, Survey Study, randomly selected 7 slickens within GRKC, each paired with a vegetated area within 20 m of the slicken.
- Soil analysis performed with ICP-AES by Colorado State University.

- 'Emergence rates of E. *crusgalli* seedlings that germinated in limed (pH=6.6) slicken soil were not significantly different (p=0.3136) than those obtained from seedlings that germinated in acidic (pH=3.8) artificial soil...The root lengths of seedlings in the limed slicken soil, however, were significantly inhibited (p<0.0001) relative to the root lengths of seedlings in the uncontaminated artificial soil.' (p 29)

  'No visible soil biota (oligochaetes, nematodes, arthropods or mollusks) were found in any soil samples collected for this study...Earthworm survival was significantly reduced in slicken soils and earthworms displayed avoidance of the most dilute sample tested, the 3.13% slicken soil dilution...ln short, the riparian ecosystem is clearly disrupted and the slicken areas are essentially biologically dead.' (p 30-31)

- 'Until upstream deposits of contaminated materials can be removed or stabilized, revegetation of slicken areas on the Grant-I<ohrs Ranch should be considered only a temporary solution.' (p 31)
- 'A. gigantea was the most sensitive of the four species tested, with a 9.2% slicken soil necessary to cause a 50% reduction in the emergence of redtop bentgrass seedlings.' (p 32)
- 'The results of the previous section, indicating that pH may be controlling the toxicity of floodplain soils, lead us to wonder if the toxicity we had measured in the slicken soils could be exclusively attributed to pH? In order to address this question, we conducted a germination experiment with uncontaminated, acidic artificial soil with a pH=3.8. This pH value was lower than any measured in natural soils collected from the Grant-Kohrs Ranch, Three replicates germinated with a mean of 33 seeds emerging out of a possible 40, or an 82.5% emergence rate, significantly higher that the 0% emergence rate obtained from acidic (pH=4.6) slicken soils...this test confirmed that the toxicity we observed was not solely pH induced. Rather, the toxic response appears to require both acidic conditions and elevated concentrations of metals.' (p 34-35)

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10. Rader, Brian R.; Nimmo, Dr. Delwayne R. and Chapman, Dr. Phillip L. *The Influence of Heavy Metal Concentrations and pH on the Toxicity of Contaminated Floodplain* Soils *from the Grant-Kohrs* Ranch *National Historic Site, Montana.* Master of Science Thesis, Colorado State University, Fort Collins, CO: December 1995 (34 pp).

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11. Rader, Brian R. and Dr. Delwayne R. Nimmo. *A Toxicological Evaluation of Floodplain Slicken* Soils *on the* Grant-Kohrs *NHS, Montana.* Conference Summary Paper (?) 7pp.

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12. Powell, Jerald M. *The Aquatic Macrophyte* Azolla mexican as *an Indicator of Cadmium, Copper, and* Zinc *Bioavailability and Toxicity from Synthetic and Natural Sediments.* Master of Science Thesis, Colorado State University, Fort Collins, CO: Spring 1996 (48 pp).

- Studied the use of *Azolla* (a heterosporous water fern) as an indicator species for Cd, Cu, and Zn toxicity in sediments.
- 'Cadmium toxicity was apparent at a concentration of 0.3 mg/L and had the greatest BCF [bioaccumulation factor] of the three metals tested individually...Metals, tested individually, reduced biomass compared to control samples in dilutions of 0.3 mg/I_ Cd, 274 mg/I_ Cu, *and* 1069 mg/L Zn.'. (p iv)
- Powell used the slicken soils samples and metals data from Brian Rader's thesis (1995).

13. DOIINPS-GRKO. *Site Evaluation Work Plan,* Grant-Kohrs Ranch *National Historic Site, Deer Lodge,* Montana. June 26, 1996.

Purpose:

1. confirm previous XRF results (i.e., Karl Ford 1994).
2. collect additional samples to determine the nature and extent of contamination (vertical),
3. determine the metal concentrations in forage,
4. determine metal concentrations in beef cattle,
5. determine the mineralogy of the site,
6. determine the net neutralization potential of floodplain sediments and soils (alternatives development),
7. collect other data to support risk assessment and remedy selection efforts.

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14. Castle, Carla J., Jerald Powell, and Del Nimmo. *Earthworm Avoidance Test Continued.* (Ref.:Rader Thesis, Chapter 3) Mid-Continent Ecological Center, Biological Resources Division, USGS, CSU Fort Collins, CO: August 7, 1996 (8 pp)

- This paper is very short, poorly written, and not very coherent.
- This short paper is additional information provided to GRKO related to earthworm avoidance tests performed by Brian Rader in his Master's thesis. While Rader discussed the results of earthworm avoidance to a series of limed artificial slickens soil dilutions, this paper presents an assessment of earthworm avoidance to a series of dilutions of soils from the 'reference sites' surrounding Rader's slickens sites (i.e., from XXX.
- 'Site soils were collected outside the "slicken", areas and tested without pH adjustment.' Soil dilution was from 0% to 50% reference site soil (referred to as 'slicken soil', but obtained from the vegetated reference sites 20 m outside of the bare slicken areas). (p ii)
- 'As in past tests, the artificial soil was preferred at the lowest slicken dilution and as the proportion of contaminated slicken soil in the treatment side of the test container was increased, the probability of the earthworms being found in the artificial control side of the test chamber also increased...mortalities in the reference/slicken [dilution of slicken soils with reference site soils] test were high in all exposures including in the reference soils.' (p Hi)
- Concludes that reference soils, i.e., soils obtained 20 m into the vegetated perimeters of bare slickens areas, are high in metals and caused high earthworm mortality. Consequently, these soils do not represent a viable option for remediation (apparently, the ideas was to dilute bare slickens with surrounding soils).

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15. Jackson, Scott. *Beef tissue samples for heavy metals analysis.* Memorandum & Attachments from Jackson, NPS-GRKO to Karl Ford, BLM-Applied Natural Resource Science Center, Denver, CO: November 1996 (12 pp).

- Muscle, kidney, and liver samples were collected from six GRKO cows on 11/1/96. Three had been grazed in the riparian zone, three in 'normal' grazing pastures, for 95 days prior to slaughter.
- Due to a veterinary delay, all 6 cattle were fed hay for 72 hours prior to slaughter.
- Beef tissues presented no hazard to human health. The cattle dosing experiment indicated that there were no significant statistical differences between cattle grazed in the fenced riparian zone and those grazed on open grasslands within the 100-year floodplain, but contaminant concentrations were found to be 2-3 times above levels normally found in beef cattle.

16. DOI/NPS-GRKO. *Revised-Final Site Evaluation* Report, Grant-Kohrs Ranch National *Historic Site, Deer Lodge, Montana (revised from 11/30/96).* August 1, 1997 (22 pp & 141 pp addendum).

- Copy provided to EPA Administrative Record, Helena..
- Original version (11/30/96) was submitted to EPA and reviewed by Dennis Neuman of MSU/RRU. Neuman's review called for more methodological detail, questioned the use of XRF data (Karl Ford 1994 and 1996) for quantitative purposes, critiqued the combining of vegetation tissue results from different plant species, and commented that a NRD bias existed in the discussion/interpretation section of the report.
- GRKO has been impacted by floodplain-deposited tailings resulting in bare, unvegetated riparian areas (slickens) that contain soils with a crystalline salt crust, low pH and high concentrations of arsenic, cadmium, copper, lead and zinc which are the primary Contaminants of Concern (COC). Vegetated riparian areas also contain equivalently high contaminant concentrations but more neutral pH.' (Executive Summary)
- Analyzed 41 surface floodplain sediment samples, 36 subsurface samples, 42 vegetation samples, 8 beef tissue samples, and 7 surface water samples. Also, relies heavily on Rice & Ray 1984, Rader 1995, BLM 1994, and beef tissue sampling 1996.
- Includes the results of two Karl Ford sampling events:
  - July 1996: Karl Ford [Soil boring and washed vegetation study]
  - September— October, 1996: Karl Ford [Cursory soil and water sampling at GRKO]

    A. September 6, 1996:3 GRKO water samples collected (plus one duplicate)

    1. GK-EF-01 Effluent sample from outfall of sewage lagoons to CFR
    2. GK-SL-01 Slickens runoff to CFR (beaver activity = 2-3 wks of flow) Co-located with a soil pit dug by backhoe in July 1996
    3. GK-SL-02 Duplicate sample of GK-SL-01
    4. GK-RI-01 Riparian surface water 100' up gradient from slicken, near beaver impoundment

    B. October 2-11, 1996: sampled 5 GRKO riparian soil profiles,(0-28")
- Using the 1994 XRF data, corrected for bias, the estimated acreage's [sic] exceeding the Rice and Ray arsenic and copper criteria is 190 acres and 702 acres respectively. However, based on earthworm studies and literature sources, the Rice and Ray criteria may not be fully protective for ecological receptors at GRKO.' (Executive Summary)
- '...concentrations of the COC decrease in slickens significantly at three feet below ground surface. Similarly, the acid generation potential of the floodplain sediments decreases significantly at three feet.' (Executive Summary)
- Vegetation results show statistically higher concentrations in the riparian vs. the irrigated pastures and in unwashed samples vs. washed samples...A significant correlation was observed between soil and plant concentrations for cadmium, copper and zinc.' (Executive Summary)
- 'Trapping of small mammals in the riparian area indicated a 86% reduction of small mammals when compared to the upland pastures and that cadmium tissue concentrations appeared higher than normal.' (p 2)
- The slickens soil pH averages 4-5 and pH contributes more to plant and earthworm toxicity than metal concentrations as shown by field studies and laboratory root germination and elongation studies.' (p 2)
- 'These data indicate that removal of 3' of contaminated overburden should meet the Rice and Ray criteria and arsenic at 25 ppm [sic].' (p 12)
- '...several pasture cows had cadmium kidney concentrations above normal, liver copper in one riparian cow was at the toxic level and all three riparian cows and one pasture cow had muscle copper concentrations above nonnal.' (p 15)

- Arsenic and cadmium concentrations in GRKO cattle kidney and liver are elevated by 2- to 3-fold; kidney copper is not elevated but several liver copper results are elevated by 2- to 3-fold; and kidney and liver zinc are slightly elevated.' (p 15)

Discussion:

- 1994 XRF data should be considered semi-quantitative due to variability in regression statistics.
- The XRF data confirm the Rice & Ray 1984 and Rader 1995 results.
- Using XRF data, corrected for XRF bias, approximately 190 acres exceed the Rice and Ray criterion for arsenic and 702 acres exceed the Rice and Ray criterion for copper.' (p 16)
- While the results of the soil and plant tissue sampling suggest that the Rice and Ray soil and vegetation criteria are protective of beef for human consumption, they may not be adequate for protection of plants, soil macrofauna (e.g. earthworms) and their consumers and may impair the ability of soil macrofauna to cycle nutrients in the soil (Beyer, 1993; Jongbloed et al, 1996; Rader, 1995). For example, Van Rhee (1975) showed that 110 ppm copper is toxic to earthworms. Additionally, acid soils may compromise the Rice and Ray criteria and a cautionary level may be required for pH. Based on plant toxicity, a cautionary level of pH 7.0 minimizes plant toxicity.' (p 16)
- The important finding in the ABA results is that most of the acid generating potential of the tailings in the slickens is limited to the upper three feet' (p 16).
- 'Runoff samples showed extremely high concentrations of the COC, acid pH and high total dissolved solids (salts). These findings, along with bioaccessibility findings, show that the COC in the crystals represent a serious threat to aquatic life in the Clark Fork River.' (p 16)
- Microprobe results show Fe(M) oxide is the dominant arsenic species in the samples analyzed by microprobe. According to John Drexler, Fe(M) oxide is a dominant metal bearing phase found in flue and roaster dusts, associating it with smelting activities upstream. In addition, slag is found in slickens sample SB-5, associating it with smelting activities. The white crystals found on the surface of slickens (Attachmentl1) are primarily calcium sulfate (gypsum), with high concentrations of copper and zinc...the GRKO arsenic is a combination of sulfate, sulfide associated with the base ore with lesser amounts of oxide, principally deposited as floodplain tailings along the Clark Fork River. These results support the findings of others that the surface material is highly soluble, bioavailable and toxic to aquatic life when precipitation runoff flows into the Clark Fork River.' (p 16-17)
- Based on XRF results, many vegetated areas (slickens) have equivalently high COC concentrations but more neutral pH...Significant bioaccumulation of cadmium, copper and zinc was observed in riparian vegetation...upland pasture forage COC concentrations do not exceed . Rice and Ray criteria and are considered safe for cattle and wildlife consumption.' (p 17)
- Small animal trapping in the riparian area indicated a 86% reduction in catch when compared to upland pasture and target organ cadmium was elevated (Rice and Ray, 1984). Soil cadmium concentrations are well above concentrations known to cause toxicity in terrestrial food chains, particularly to those consumers of earthworms and other soil invertebrates (Jongbloed et al, 1996).' (p 17)

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17. Powell, Jerald M., Delwayne Nimmo, Stephen A:Flickinger, and Stephen F. Brinkman. 'Use of Azolla to assess toxicity and accumulation of metals from artificial and natural sediments containing cadmium, copper and zinc.' American Society for Testing and Materials. Fall 1997 (15 pp).

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18. ecological planning and toxicology, inc. *Report on Histopathology,* Earthworm *Mortality, and Early Seedling Growth Studies. Completed in support of a NPS/BLM Clark Fork River Preliminary Ecological Effects* Study, Deer *Lodge, MT.* For Bureau of Land Management, National Applied Resource Science Center, Denver, CO November 11, 1997 (17 pp, Appendix 219 pp).

- Part 2 of the Preliminary Ecological Effects Study (transect study below) performed by Karl Ford on GRKO and BLM parcels.
- ep and it to perform 5 tasks
    1. In-field necropsy and sample preparation of small mammals and birds
    2. Submission of small animal kidney and liver samples for histopathology
    3. Early seedling growth and earthworm mortality testing of sails from the study and reference areas
    4. Submission of soils, vegetation, and small animal samples for As, Cd, Cu, Pb, and Zn lab testing
    5. Small mammal LC_{50} test (discussed separately)
- Of the 30 small mammal and bird specimens submitted for histopathology, 'No effects or deformities consistent with metals exposure were noted.' (Executive Summary, p i) 'This level of parasitic activity likely falls within a range normal for wild populations of small mammals.' (p 3)
- Using test dilution series with soil samples from two GRKO dickens transects and two BLM tract transects, performed early seedling growth tests and earthworm mortality tests.
- A reference site transect was established on the Little Blackfoot River.
- In general early seedling growth was negatively impacted at the 100% transect soils, with decreasing effects as transect soils were diluted.
- Only one transect soil (a GRKO slicken sample) exhibited high earthworm mortality, possibly due to lower pH of that soil.
- The low n value and limited endpoints measured in these studies made statistical analysis problematic and provided little in the *way* of scientific conclusion.

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19. Ford, Karl. *Clark Fork River Preliminary Ecological Effects Study*. UDSI BLM, 'National Applied Resource Sciences Center, Denver CO: November 1997 (5 pp).

- Two part study:
    1. Reconnaissance study to evaluate slickens areas: 1 reference site (Little Blackfoot River='T-3'), 4 study sites (2 GRKO='T-l' & 'T-2'; 2 BLM='T-4' & 'T-5'). Samples collected August 18-21, 1997.
    2. Toxicity and residue testing [earthworm toxicity, root germination/elongation (phytotoxicity), small mammal toxicity, & plant/wildlife tissue sampling and residue analysis (see ep and t, Histopathology Report)].

  Karl Ford provided this data to EPA for use in the CFR Ecological Risk Assessment, Appendix H: 'Detailed Calculation of Exposure and Hazard for Terrestrial Receptors at Grant-Kohrs Ranch National Historic Site.'

  August 18-21, 1997: Karl Ford -- Preliminary Ecological Effects Study (see part 1, above)

  - 2 GRKO slickens transects: SB-5 (Transect 1) and SB-2 (Transect 2) (ID #s from Ford, 1996)
  - Transect 3 = reference site along Little Blackfoot River b/n Elliston and Avon
  - 2 BLM transects: Tract 4 (Transect 4) and Tract 5 (Transect 5)
  - Each transect composited for soil (0-2") and plant tissue

20. Troup, Robert and Karl Ford. *Dietary Toxicity (LC50) of Soil Samples from the Clark Fork Site with White-footed Mice (Peromyscus* leucopus). ep and t #BLMCFDM-97-1. ecological planning and toxicology, inc., Corvallis, OR. Sponsor: BLM, Denver, CO: November 1997 (36 pp).

- Part of the Preliminary Ecological Effects Study (transect study) performed by Karl Ford on GRKO and BLM parcels.
- Mouse toxicity study had methodological problems and was not included in final ep and t histopathology report.

21. Guthrie, Jeralyn and Richard Cheatham. *Inorganic* Data *Validation Reports and Sample Results for Grant-Kohrs Ranch Soil Samples.* C.C. Johnson & Malhotra, P.C. Lakewood, CO: March 1998 (138 PP).

22. Data Validation Summary Report. Foster Wheeler Environmental Corporation, Lakewood, CO: August 1999 (10 p text & 25 p appendix)

- Summarizes data validation procedures and results associated with soil samples collected by NPS personnel in July 1998 (Jim Ford) and analyzed by Laucks Testing Laboratories, Seattle, WA (a subcontract for C. C. Johnson and XXX) in March 1998.
- 206 soil samples taken at varying depths from 77 soil borings at 6" intervals up to 42"
- Samples analyzed for As, Cd, Cu, Pb, and Zn by ICP.and for Hg by CVAA; plus 45 of these were selected for TCLP analysis
- Performed data validation on 100% of data set according to EPA CLP guidelines
- All mercury data was J-qualified (exceeded the 28-day holding time)
- GKR10 all J-qualified (exceeded linear calibration range and were not diluted)
- J-qualified = estimated values
- All TCLP barium results B-qualified (contamination of TCLP extraction blanks)
- No equipment rinse blank samples were, collected
- Numerous GKR groups were J-qualified due to recoveries outside method control limits or due to differences between serial dilution samples and field samples
- No field duplicates were collected
- Several GKR sample groups were J-qualified for excessive lab duplicate and field sample differences
- 37% of data J-qualified
- 1.3% of data R-qualified
- 2.8% of data B- or BJ-qualified
- 'Overall, precision and accuracy for the analytical data were acceptable, and valid conclusions may be drawn from the field sample data.' (p 10)

APPENDIX B. COMPILATION OF PREDOMINANT SPECIES IN BASELINE TYPE COMMUNITIES

Water Birch (BETOCC) community type native species list.

Species	Common Name	%CC
Betula occidentalis	Water Birch	51.25
Alnus incana	Mountain Alder	7.89
Prunus virginiana	Common Chokecherry	4.55
Equisetum laevigatum	Smooth Scouring Rush	4.02
Carex nebraskensis	Nebraska Sedge	3.77
Urtica dioica	Stinging Nettle	3.77
Cornus stolonifera	Red Osier Dogwood	3.55
Rosa woodsii	Woods Rose	3.45
Smilacina stellata	Starry Solomon Plume	2.93
Symphoricarpos albus	Common Snowberry	2.86
Equisetum arvense	Field Horsetail	2.77
Helianthus nuttallii	Nuttall's Sunflower	2.75
Rosa sp.	Rose	2.27
Aster sp.	Aster	2.00
Juncus balticus	Baltic Rush	2.00
Equisetum hyemale	ScouringRush	1.84
Veronica americana	American Speedwell	1.82
Salix bebbiana	Bebb Willow	1.64
Epilobium ciliatum	Common Willow Herb	1.41
Amelanchier alnifolia	Western Serviceberry	1.36
Solidago canadensis	Canada Goldenrod	1.18
Galium boreale	Northern Bedstraw	1.11
Apocynum androsaemifolium	Spreading Dogbane	1.05
Disporum trachycarpum	Wartberry Fairy Bell	1.05

Sandbar Willow (SALEXI) community type native species list.

Species	Common Name	Origin	%CC
Salix exigua	Sandbar Willow	N	60.35
Rosa woodsii	Woods Rose	N	8.36
Symphoricarpos occidentalis	Western Snowberry	N	4.69
Equisetum arvense	Field Horsetail	N	4.31
Cornus stolonifera	Red Osier Dogwood	N	3.37
Glycyrrhiza lepidota	Wild Licorice	N	2.28
Polygonum amphibium	Water Smartweed	N	1.79
Solidago canadensis	Canada Goldenrod	N	1.76
Agropyron smithii	Western Wheat Grass	N	1.68
Mentha arvensis	Field Mint	N	1.50
Carex rostrata	Beaked Sedge	N	1.26
Apocynum cannabinum	Hemp Dogbane	N	1.14
Agrostis stolonifera	Creeping Bent Grass	E	8.75

Geyer Willow / Beaked Sedge (SALGEY/CARROS) habitat type native species list.

Species	Common Name	%CC
Carex rostrata	Beaked Sedge	34.81
Salix geyeriana	Geyer Willow	24.53
Salix boothii	Booth Willow	15.76
Carex aquatilis	Water Sedge	8.51
Salix wolfii	Wolf's Willow	4.14
Salix planifolia	Planeleaf Willow	3.19
Calamagrostis canadensis	Bluejoint Reed Grass	3.15
Salix bebbiana	Bebb Willow	3.07
Juncus balticus	Baltic Rush	2.97
Salix drummondiana	Drummond Willow	2.89
Potentilla fruticosa	Shrubby Cinquefoil	2.83
Geum macrophyllum	Large Leaved Avens	2.67
Equisetum arvense	Field Horsetail	2.44
Aster occidentalis	Western Aster	2.31
Deschampsia cespitosa	Tufted Hair Grass	2.21
Epilobium ciliatum	Common Willow Herb	1.99
Carex vesicaria	Inflated Sedge	1.86
Betula glandulosa	Bog Birch	1.81
Agrostis scabra	Tickle Grass	1.78
Galium trifidum	Small Bedstraw	1.50
Mentha arvensis	Field Mint	1.26
Glyceria striata	Fowl Manna Grass	1.20
Carex disperma	Soft Leaved Sedge	1.19
Fragaria virginiana	Wild Strawberry	1.14
Aster foliaceus	Leafy Aster	1.09
Carex lanuginosa	Woolly Sedge	1.09

Beaked Sedge (CARROS) community type native species list.

Species	Common Name	%CC
Carex rostrata	Beaked Sedge	42.82
Carex vesicaria	Inflated Sedge	14.04
Carex atherodes	SugarGrass Sedge	6.75
Carex aquatilis	Water Sedge	6.36
Juncus balticus	Baltic Rush	1.58
Potentilla palustris	Purple Cinquefoil	1.51
Deschampsia cespitosa	Tufted Hair Grass	1.46
Calamagrostis canadensis	Bluejoint Reed Grass	1.17
Polygonum amphibium	Water Smartweed	1.07
Equisetum fluviatile	Water Horsetail	1.04
Mentha arvensis	Field Mint	1.03
Eleocharis palustris	Creeping Spike Rush	1.00

Snowberry (SYMOCC) community type native species list.

Species	Common Name	%CC
Symphoricarpos occidentalis	Western Snowberry	60.96
Rosa woodsii	Woods Rose	7.64
Agropyron smithii	Western Wheat Grass	6.27
Toxicodendron rydbergii	Western Poison Ivy	2.76
Prunella vulgaris	Healall	1.71
Urtica dioica	Stinging Nettle	1.70
Symphoricarpos albus	Common Snowberry	1.58
Phragmites australis	Common Reed	1.51
Artemisia ludoviciana	Louisiana Wormwood	1.49
Glycyrrhiza lepidota	Wild Licorice	1.33
Lactuca oblongifolia	Blue Lettuce	1.26
Galium boreale	Northern Bedstraw	1.25
Muhlenbergia racemosa	Satin Grass	1.25
Elymus canadensis	Canada Wildrye	1.20
Solidago canadensis	Canada Goldenrod	1.20
Calamovilfa longifolia	Prairie Sand Reed	1.13
Agropyron caninum	Bearded Wheat Grass	1.10

Slender Sedge (CARLAS) habitat type native species list.

Species	Common Name	%CC
Carex lanuginosa	Woolly Sedge	21.38
Carex lasiocarpa	Woolfruit Sedge	19.70
Juncus balticus	Baltic Rush	5.81
Carex buxbaumii	Buxbaum's Sedge	4.06
Potentilla anserina	Silverweed Cinquefoil	2.64
Carex nebraskensis	Nebraska Sedge	2.50
Potentilla palustris	Purple Cinquefoil	1.89
Carex livida	Pale Sedge	1.88
Carex paupercula	Poor Sedge	1.88
Calamagrostis stricta	Narrow Spiked Reed Grass	1.83
Carex rostrata	Beaked Sedge	1.55
Deschampsia cespitosa	Tufted Hair Grass	1.45
Eleocharis palustris	Creeping Spike Rush	1.27
Cicuta maculata	Spotted Waterhemlock	1.25
Equisetum arvense	Field Horsetail	1.25
Equisetum variegatum	Variegated Horsetail	1.25
Juncus nevadensis	Sierra Rush	1.25
Scirpus pungens	Sharp Bulrush	1.25
Aster occidentalismar	Western Aster	1.05
Carex interior	Inland Sedge	1.03

Tufted Hair Grass (DESCES) habitat type native species list.

Species	Common Name	%CC
Deschampsia cespitosa	Tufted Hair Grass	30.57
Juncus balticus	Baltic Rush	10.40
Senecio integerrimus	Western Groundsel	4.61
Aster occidentalis	Western Aster	3.94
Equisetum variegatum	Variegated Horsetail	2.87
Phleum alpinum	Alpine Timothy	2.31
Danthonia intermedia	Timber Oat grass	2.10
Aster foliaceus	Leafy Aster	2.09
Carex pachystachya	Thick Headed Sedge	2.01
Hordeum brachyantherum	Meadow Barley	1.84
Fragaria virginiana	Wild Strawberry	1.80
Caltha leptosepala	Elkslip Marshmarigold	1.71
Ligusticum tenuifolium	Slender leafed Licorice root	1.53
Geum macrophyllum	Large Leaved Avens	1.37
Carex aquatilis	Water Sedge	1.24
Carex vesicaria	Inflated Sedge	1.24
Carex praegracilis	ClusteRed Field Sedge	1.17
Arnica chamissonis	Meadow Arnica	1.16
Aster chilensis	Long Leaved Aster	1.14
Achillea millefolium	Common Yarrow	1.04

Water Sedge (CARAQU) habitat type native species list.

Species	Common Name	%CC
Carex aquatilis	Water Sedge	49.73
Deschampsia cespitosa	Tufted Hair Grass	5.83
Carex simulata	Short reba Sedge	3.39
Carex lenticularis	Lentil Fruited Sedge	3.33
Carex aperta	Columbia Sedge	2.84
Eleocharis pauciflora	Few FloweredSpike-rush	2.73
Juncus balticus	Baltic Rush	2.41
Carex rostrata	Beaked Sedge	1.95
Calamagrostis stricta	Narrow Spiked Reed Grass	1.73
Eleocharis palustris	Creeping Spike Rush	1.32
Carex vesicaria	Inflated Sedge	1.07

Chokecherry (PRUVIR) community type native species list.

Species	Common Name	%CC
Prunus virginiana	Common Chokecherry	47.42
Symphoricarpos occidentalis	Western Snowberry	12.24
Oryzopsis micrantha	Little seed Rice Grass	9.62
Rosa woodsii	Woods Rose	9.58
Clematis ligusticifolia	Western Clematis	5.90
Carex sprengelii	Sprengel's Sedge	5.72
Galium boreale	Northern Bedstraw	4.48
Elymus virginicus	Virginia Wildrye	4.24
Smilacina stellata	Starry Solomon Plume	3.94
Agropyron smithii	Western Wheat Grass	3.60
Ribes odoratum	Buffalo Currant	3.42
Toxicodendron rydbergii	Western Poison Ivy	2.94
Coreopsis tinctoria	Plains Coreopsis	2.00
Rhus aromatica	Fragrant Sumac	1.88
Apocynum androsaemifolium	Spreading Dogbane	1.60
Elymus villosus	Hairy Wildrye	1.60
Urtica dioica	Stinging Nettle	1.34
Amelanchier alnifolia	Western Serviceberry	1.32
Crataegus douglasii	Black Hawthorn	1.32
Fragaria vesca	Woods Strawberry	1.22
Scirpus pungens	Sharp Bulrush	1.20
Achillea millefolium	Common Yarrow	1.00

Cattail (TYPLAT) habitat type native species list.

Species	Common Name	%CC
Typha latifolia	Common Cattail	69.91
Typha angustifolia	Narrowleaf Cattail	14.57
Scirpus validus	Softstem Bulrush	1.90
Polygonum amphibium	Water Smartweed	1.32
Mentha arvensis	Field Mint	1.27

Drummond Willow/Beaked Sedge (SALDRU/CARROS) habitat type native species list.

Species	Common Name	%CC
Salix drummondiana	Drummond Willow	40.53
Carex rostrata	Beaked Sedge	28.62
Salix boothii	Booth Willow	6.22
Calamagrostis canadensis	Bluejoint Reed Grass	5.93
Carex aquatilis	Water Sedge	4.49
Alnus incana	Mountain Alder	4.06
Carex canescens	Gray Sedge	3.05
Geum macrophyllum	Large Leaved Avens	2.78
Carex vesicaria	Inflated Sedge	2.57
Betula glandulosa	Bog Birch	2.48
Equisetum arvense	Field Horsetail	2.15
Polygonum amphibium	Water Smartweed	2.10
Potentilla palustris	Purple Cinquefoil	2.05
Mentha arvensis	Field Mint	1.79
Aster occidentalis	Western Aster	1.77
Salix bebbiana	Bebb Willow	1.64
Cornus stolonifera	Red Osier Dogwood	1.43
Petasites sagittatus	Arrowleaf Coltsfoot	1.42
Epilobium ciliatum	Common Willow Herb	1.35
Juncus balticus	Baltic Rush	1.31
Ribes sp.	Currant	1.29
Agrostis scabra	Tickle Grass	1.19
Aster modestus	Few FloweredAster	1.12
Bromus ciliatus	Fringed Brome	1.03
Rhamnus alnifolia	Alder Buckthorn	1.03

SpikeSedge (ELEPAL) habitat type native species list.

Species	Common Name	%CC
Eleocharis palustris	Creeping Spike Rush	51.59
Eleocharis acicularis	Needle Spike Rush	11.64
Hordeum jubatum	Foxtail Barley	2.63
Sparganium emersum	Simplestem Bur Reed	2.01
Senecio hydrophilus	Alkali Marsh Butterweed	1.72
Carex unilateralis	One Sided Sedge	1.67
Agropyron smithii	Western Wheat Grass	1.34
Alopecurus aequalis	Short Awn Foxtail	1.18
Beckmannia syzigachne	American Slough Grass	1.16
Sagittaria cuneata	Wedgeleaf arrowhead	1.02
Carex athrostachya	Slender Beaked Sedge	1.00
Juncus tracyi	Tracy's Rush	1.00
Puccinellia nuttalliana	Nuttall's Alkali Grass	1.00

Geyer Willow / Bluejoint ReedGrass (SALGEY/CALCAN) habitat type native species list.

Species	Common Name	%CC
Salix geyeriana	Geyer Willow	21.59
Salix boothii	Booth Willow	19.81
Calamagrostis canadensis	Bluejoint Reed Grass	11.56
Calamagrostis stricta	Narrow Spiked Reed Grass	7.10
Salix drummondiana	Drummond Willow	4.53
Solidago canadensis	Canada Goldenrod	3.81
Juncus balticus	Baltic Rush	2.71
Deschampsia cespitosa	Tufted Hair Grass	2.62
Fragaria virginiana	Wild Strawberry	2.31
Salix wolfii	Wolf's Willow	2.25
Salix bebbiana	Bebb Willow	2.24
Betula occidentalis	Water Birch	2.19
Geum macrophyllum	Large Leaved Avens	2.13
Cornus stolonifera	Red Osier Dogwood	2.07
Aster occidentalis	Western Aster	2.06
Equisetum arvense	Field Horsetail	1.85
Betula glandulosa	Bog Birch	1.78
Salix tweedyi	Tweedy's Willow	1.76
Polemonium occidentale	Western Polemonium	1.66
Alnus incana	Mountain Alder	1.56
Heracleum lanatum	Cow Parsnip	1.51
Glyceria striata	Fowl Manna Grass	1.50
Salix exigua	Sandbar Willow	1.47
Scirpus microcarpus	Small Flowered Bulrush	1.47
Achillea millefolium	Common Yarrow	1.44
Epilobium angustifolium	Fireweed	1.32
Aster foliaceus	Leafy Aster	1.28
Valeriana edulis	Edible Valerian	1.26
Ribes sp.	Currant	1.19
Rosa acicularis	Prickly Rose	1.19
Aster sp.	Aster	1.18
Bromus ciliatus	Fringed Brome	1.18
Rhamnus alnifolia	Alder Buckthorn	1.18
Potentilla fruticosa	Shrubby Cinquefoil	1.12
Carex pachystachya	Thick Headed Sedge	1.00

Yellow Willow / Bluejoint ReedGrass (SALLUT/CALCAN) habitat type native species list.

Species	Common Name	%CC
Salix bebbiana	Bebb Willow	32.60
Juncus balticus	Baltic Rush	16.00
Calamagrostis canadensis	Bluejoint Reed Grass	12.00
Salix lutea	Yellow Willow	10.70
Cornus stolonifera	Red Osier Dogwood	8.10
Betula glandulosa	Bog Birch	8.00
Antennaria anaphaloides	Tall Pussy Toes	4.00
Potentilla fruticosa	Shrubby Cinquefoil	4.00
Deschampsia cespitosa	Tufted Hair Grass	2.70
Mentha arvensis	Field Mint	2.10
Viola sp.	Violet	2.10
Agropyron caninum	Bearded Wheat Grass	2.00
Arctostaphylos uva-ursi	Kinnikinnick	2.00
Artemisia lindleyana	Riverbank Wormwood	2.00
Carex sartwellii	Sartwell's Sedge	2.00
Equisetum laevigatum	Smooth Scouring Rush	2.00
Fragaria virginiana	Wild Strawberry	2.00
Galium boreale	Northern Bedstraw	2.00
Gentiana affinis	Pleated Gentian	2.00
Hieracium gracile	Alpine Hawkweed	2.00
Muhlenbergia filiformis	Slender Muhly	2.00
Salix brachycarpa	Short Fruited Willow	2.00
Rosa woodsii	Woods Rose	1.30
Aster chilensis	Long Leaved Aster	1.20

Yellow Willow / Beaked Sedge (SALLUT/CARROS) habitat type native species list.

Species	Common Name	%CC
Carex rostrata	Beaked Sedge	27.14
Salix lutea	Yellow Willow	22.86
Carex aquatilis	Water Sedge	14.50
Salix bebbiana	Bebb Willow	9.93
Equisetum arvense	Field Horsetail	7.89
Juncus balticus	Baltic Rush	6.18
Betula occidentalis	Water Birch	5.71
Salix candida	Hoary Willow	5.71
Betula glandulosa	Bog Birch	5.25
Carex vesicaria	Inflated Sedge	5.00
Cornus stolonifera	Red Osier Dogwood	4.07
Potentilla fruticosa	Shrubby Cinquefoil	3.39
Carex interior	Inland Sedge	2.86
Galium triflorum	Sweetscented Bedstraw	2.86
Salix geyeriana	Geyer Willow	2.86
Salix planifolia	Planeleaf Willow	2.79
Deschampsia cespitosa	Tufted Hair Grass	2.43
Salix serissima	Autumn Willow	2.36
Viola sp.	Violet	2.29
Salix glauca	Glaucous Willow	2.14
Calamagrostis stricta	Narrow Spiked Reed Grass	1.93
Solidago canadensis	Canada Goldenrod	1.68
Carex nebraskensis	Nebraska Sedge	1.46
Aster sp.	Aster	1.43
Calamagrostis canadensis	Bluejoint Reed Grass	1.43
Carex lanuginosa	Woolly Sedge	1.43
Carex praegracilis	ClusteRed Field Sedge	1.43
Mimulus guttatus	Common monkey flower	1.43
Petasites sagittatus	Arrowleaf Coltsfoot	1.43
Salix pseudomonticola	Mountain Willow	1.43

Bluejoint ReedGrass (CALCAN) habitat type native species list.

Species	Common Name	%CC
Calamagrostis canadensis	Bluejoint Reed Grass	28.63
Calamagrostis stricta	Narrow Spiked Reed Grass	26.18
Senecio triangularis	Arrowleaf Groundsel	3.62
Deschampsia cespitosa	Tufted Hair Grass	3.41
Juncus balticus	Baltic Rush	2.97
Eleocharis rostellata	Beaked Spike Rush	2.57
Aster occidentalis	Western Aster	1.88
Pedicularis groenlandica	Elephant's Head	1.68
Senecio integerrimus	Western Groundsel	1.66
Helianthus tuberosus	Jerusalem Artichoke	1.58
Carex aquatilis	Water Sedge	1.41
Viola sp.	Violet	1.39
Ligusticum tenuifolium	Slender Leafed Licorice root	1.32
Heracleum lanatum	Cow Parsnip	1.14
Alopecurus alpinus	Alpine Foxtail	1.13
Agrostis scabra	Tickle Grass	1.08
Trisetum wolfii	Wolf's Trisetum	1.08
Angelica arguta	Sharptooth Angelica	1.07
Senecio pseudaureus	Streambank Groundsel	1.07

Black Cottonwood / Red-Osier Dogwood (POPTRI/CORSTO) community type species list.

Species	Common Name	%CC
Populus trichocarpa	Black Cottonwood	57.02
Cornus stolonifera	Red Osier Dogwood	36.95
Rosa woodsii	Woods Rose	11.38
Symphoricarpos occidentalis	Western Snowberry	8.60
Prunus virginiana	Common Chokecherry	6.19
Betula occidentalis	Water Birch	4.29
Alnus incana	Mountain Alder	3.36
Symphoricarpos sp.	Snowberry	3.33
Smilacina stellata	Starry Solomon Plume	3.21
Equisetum arvense	Field Horsetail	3.02
Symphoricarpos albus	Common Snowberry	3.00
Solidago canadensis	Canada Goldenrod	2.93
Rosa acicularis	Prickly Rose	2.88
Salix bebbiana	Bebb Willow	2.81
Rosa sp.	Rose	2.60
Osmorhiza chilensis	Spreading Sweetroot	2.55
Amelanchier alnifolia	Western Serviceberry	2.38
Actaea rubra	Red Baneberry	1.93
Equisetum sylvaticum	Sylvan Horsetail	1.90
Galium triflorum	Sweetscented Bedstraw	1.90
Spiraea douglasii	Douglas's Spiraea	1.90
Elymus glaucus	Blue Wildrye	1.50
Calamagrostis canadensis	Bluejoint Reed Grass	1.48
Lysimachia ciliata	Fringed Lloosestrife	1.45
Salix exigua	Coyote Willow	1.45
Rubus idaeus	Common Red raspberry	1.43
Aster occidentalis	Western Aster	1.10
Clematis ligusticifolia	Western Clematis	1.02
Senecio pseudaureus	Streambank Groundsel	1.00
Thalictrum occidentale	Western Meadowrue	1.00

APPENDIX C. CROSS-LIST OF SURFACE SOIL SAMPLE CODES

Codes used in geochemistry reports and data files SS-xxx were identified as MT-xx (2000) and MP-xxx (2001) in phytotoxicity and microbial assessment studies.

Soil Sample Numbers	MP Sample Number	MT Sample Numbers
SS-00		MT-06
SS-1 through SS-6	N.A.	
SS-7	MP-07	MT-10
SS-8 through SS-17	N.A.	
SS-18	MP-18	MT-05
SS-19	MP-19	
SS-20	MP-20	
SS-21	MP-22	
SS-22 through SS-23	N.A.	
SS-24	MP-24	
SS-25 through SS 32	N.A.	
SS-33	MP-33	MP-14
SS-34	MP-34	
SS-35	MP-35	
SS-36	MP-36	
SS-37 through SS-41	N.A.	
SS-42	MP-42	
SS-43 through SS-50	N.A.	
SS-51	MP-51	MT-11
SS-52	N.A.	
SS-53	MP-53	
SS-54	MP-54	MT-12
SS-55	N.A.	
SS-56	MP-56	
SS-57	MP-57	
SS-58	MP-58	MT-08
SS-59	MP-59	
SS-60	MP-60	
SS-61	MP-61	MT-07
SS-62 through SS-64	N.A.	
SS-65	MP-65	
SS-66	MP-66	
SS-67	MP-67	MT-02
SS-68	MP-68	
SS-69	MP-69	
SS-70	MT-70	
SS-71	MP-71	
SS-72	MP-72	
SS-73 through SS-76	N.A.	
SS-77	MP-77	MT-10
SS-78	MP-78	
SS-79	MP-79	
SS-80 through SS-81	N.A.	
SS-82	MP-82	MT-01
SS-83 through SS-91	N.A.	
SS-92	MP-92	MT-09
SS-93 through SS-97	N.A.	
SS-98	MP-98	MT-04
SS-99	MP-99	MT-03
SS-100	MP-100	
SS-101 through SS-111	N.A.	